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TRANSVERSE SHEAR STIFFNESS OF T300/5208 GRAPHITE-EPOXY IN SIMPLE BENDING

By: *P.E. Sandorff, Staff Engineer*
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FOREWORD

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TABLE OF CONTENTS

ABSTRACT

Buckling and crippling of a structural element is governed by its elastic properties. Nevertheless, a complete definition of the elastic constants of a graphite/epoxy laminate, including the transverse shear moduli (important under high compressive stress), has never been accomplished. For this purpose, tension, compression, and bending tests were conducted on square-section specimens cut 0-degrees and 90-degrees to the fiber axis from 64-ply unidirectional T300/5208 laminate. Axial test specimens were instrumented with tee gages to obtain data on extensional moduli and Poisson's ratios. Bending deflections were measured with high precision and analyzed using a rigorous finite difference solution for stress distribution to derive the shear moduli along with the extensional moduli acting in bending. Redundant determinations were obtained for the nine elastic constants of Hooke's law as generalized for specially orthotropic material.

Extensional moduli obtained under axial load and in bending agreed with each other to within one percent. A self-consistent set of properties was determined which were generally in accordance with published data, and which established the material as being transversely isotropic and conforming to the linear theory of elasticity. The value obtained for the shear modulus G_{12} ($=G_{13}$) was 4500 MPa (0.65 Msi), some twenty percent lower than that generally accepted on the basis of $\pm 45^{\circ}$ tension test data. The value of the transverse shear modulus G_{23} was 3650 MPa (0.53 Msi), in accordance with published results of ultrasonic tests.

INTRODUCTION

In the design and analysis of metal aircraft structures which buckle under compressive loads, and those which deform under transverse bending load, it is seldom necessary to consider the effects of shearing deformation. The transverse shear stiffness of graphite-epoxy composite laminate, however, is no more than a fifth that of aluminum alloy, and the adverse effects of shearing deformation will require consideration in many practical applications of advanced design. Reference 1, for example, indicates a reduction in compressive buckling stress of fifty percent for stiffener elements designed for high stress (width to thickness ratio of 10). An evaluation of the transverse shear modulus of this material to a reasonably high confidence level is therefore necessary for applying it efficiently in aircraft construction.

The elastic properties of composite laminate are usually represented as specially orthotropic. In this analytic model, unidirectional laminate has three shear moduli: the in-plane shear modulus G_{12}, and two transverse moduli G_{13} and G_{23}. There are several direct, relatively simple test methods for evaluating G_{12}, but very few for the transverse moduli. A selected bibliography is presented in References 2 through 15.

The most commonly used method for evaluating the in-plane shear modulus of composite laminate is the $\pm$ 45^{o} tensile test (Reference 5). In this test, a tee or rosette strain gage provides bi-directional stress-strain data; two-dimensional transformation of stresses and strains identifies shear stress vs. shear strain in the plane of the laminate. While this test is concerned only with response in the plane of the laminate, the material is usually assumed to be transversely isotropic on the basis of its structure, in which case G_{13} $=G_{12}$. Investigations have demonstrated this method to be equivalent (probably to the limitations of experimental control) to the cross-sandwich beam, thin tube in torsion, ten-deg off axis, panel shear, and rail shear tests (References 3, 6, 8). Tests of T300/5208 graphite/epoxy of 0.62-0.67 fiber volume fraction by the $\pm 45^{\circ}$ tension method have indicated G_{12} = 0.74 - 0.80 Msi (References 9,18). This value is generally understood to be the initial slope of the stress-strain relation. A possibly significant aspect of all the test methods in this category is that they usually furnish decidedly non-linear shear stress-strain curves (for example, see References 3, 6, 8, 9, and 16).

The complete set of material elastic constants can be evaluated from the speed of acoustic wave propagation in ultrasonic tests of specimens of special geometries. Such experiments indicate G_{12} and G_{13} to be about thirty percent higher than obtained with the $\pm$ 45° static tension test; Reference 7, for example, gives 1.03 Msi for this property, with G_{23} = 0.527 Msi. Engineers hesitate to use such values in design because a one-to-one relationship between microscopic dynamic oscillations and macroscopic static deformation has not been demonstrated for graphite-epoxy; indeed, even in isotropic metals, the two techniques usually provide slightly different results.

Since one of the engineering uses of the shear modulus is to improve the analytic prediction of buckling phenomena, a practical approach is to test simple buckling specimens, determine the reductions in critical load due to shear effects, and back-figure to derive applicable values of the shear moduli. This method was used to analyze some 1800 column test data in Reference 9. For T300/5208 laminate, this approach indicated room temperature values of G_{13} = 0.30 Msi and G_{23} = 0.045 Msi. Besides being unexpectedly low, these values conflict with the assumption of transverse isotropy.

In the past few years the Air Force Materials Laboratory has developed a direct test method for evaluating two of the shear moduli. This method utilizes a half-inch diameter, six-inch long cylinder cut 90 degrees to the fiber direction from thick unidirectional laminate. Shear strain gages are mounted on the surface at 0 degrees and 90 degrees to the fiber and the cylinder is loaded in torsion (Reference 12 ~~8~~). Tests of T300/5208 of fiber volume fraction 0.63 reported in Reference ~~6~~ 13 give values of 0.866 and 0.506 Msi for G_{12} and G_{23}, respectively.

Deserving of mention for its simplicity and low cost, a method known as the Iosipescu shear test has recently been applied to composite laminates (Reference 15). This test uses a specimen only slightly larger and harder to fabricate than that for the ASTM D 2344 short beam shear test, and it makes material characterization possible for both shear stiffness and strength in all three planes. The method must be confirmed by test results obtained under loading conditions realistic for structural applications, since (as with most methods) the geometry is unusual and the purity of the stress condition might be questioned.

A method that is appealing from a practical standpoint determines the shear stiffness from simple flexure tests in accordance with accepted handbook-type formulas for bending and shear deflection (References 10 and 14). Application of this method in Reference 10 indicated G_{13} of 16-ply T300/5208 laminate to be 0.40 Msi. This method suffers from the crudeness of the handbook approximation made for shear deflection, as well as from the difficulty of achieving adequate experimental precision.

The basis for an accurate analysis of flexure test data was established, in Reference 19, by the development of a computer-aided solution for the plane stress representation of a simple 3-point beam of orthotropic material. This solution provides a precise determination of the complete normal and shear stress distribution, and so permits accurate prediction of the bending and the shearing components of elastic deflection. This predictive calculation can be applied to determine the values of the elastic moduli which best fit redundant sets of deflection data obtained in flexure tests at different spans. The investigation described in this report was planned to make use of this approach, in order to evaluate the elastic constants of graphite/epoxy laminate under loading conditions representative of typical structural applications.

OBJECTIVE

The express purpose of this investigation was to evaluate the transverse shearing stiffness of T300/5208 unidirectional laminate when subjected to simple bending.

In the completion of this objective, answers to the following additional questions were also sought:

- Which if any of the existing test methods for shear modulus could be confirmed.
- What causes the disagreement among values obtained by different test methods.
- Can the material be considered transversely isotropic or not.
- Is more fundamental study required on the nature of the material and the elastic model used to represent its response.

APPROACH

Four elastic moduli govern the plane stress or plane strain response of orthotropic material. In the x-z plane these are the two extensional moduli E_{xx} and E_{zz}, the transverse shear modulus G_{xz}, and the Poisson's ratio ν_{xz}. The bending stiffness of a flexure specimen is a strong function of E_{xx}, a weak function of G_{xz}, and almost independent of E_{zz} and ν_{xz}. Therefore, two flexure tests obtained on the same beam at different spans provide sufficient information to evaluate E_{xx} and G_{xz} to good precision. To do this, however, it is necessary to relate observed deflections to the moduli through an accurate representation of the stress distribution.

The two-dimensional stress distribution for an orthotropic beam can be solved quickly and to any desired degree of accuracy by the computer-aided relaxation technique described in Reference ~~8~~ 19. This is a rigorous finite difference analysis which derives values of the stress function over a matrix of interior points to suit a specified set of boundary conditions. Once the stress function matrix is determined, stresses are readily computed, and the strains and deflections follow upon selection of the moduli.

The investigation was planned to take advantage of conventional axial load tests to identify the extensional moduli and the Poisson's ratios of a sample unidirectional laminate. Identical square section specimens cut at 0 degrees and 90 degrees to the fiber axis from 64-ply graphite-epoxy were used for all tests. A number were tested under axial load; these were instrumented with strain gages. Replicate specimens were tested in three-point bending, the stiffness being determined by measurement of central deflection. Each bending specimen provided data in two planes of loading under identical test conditions. The unreduced test data therefore furnished qualitative information regarding transverse isotropy and the relative magnitudes of G_{13} and G_{23}. The experimental approach is illustrated schematically in Figure 1.

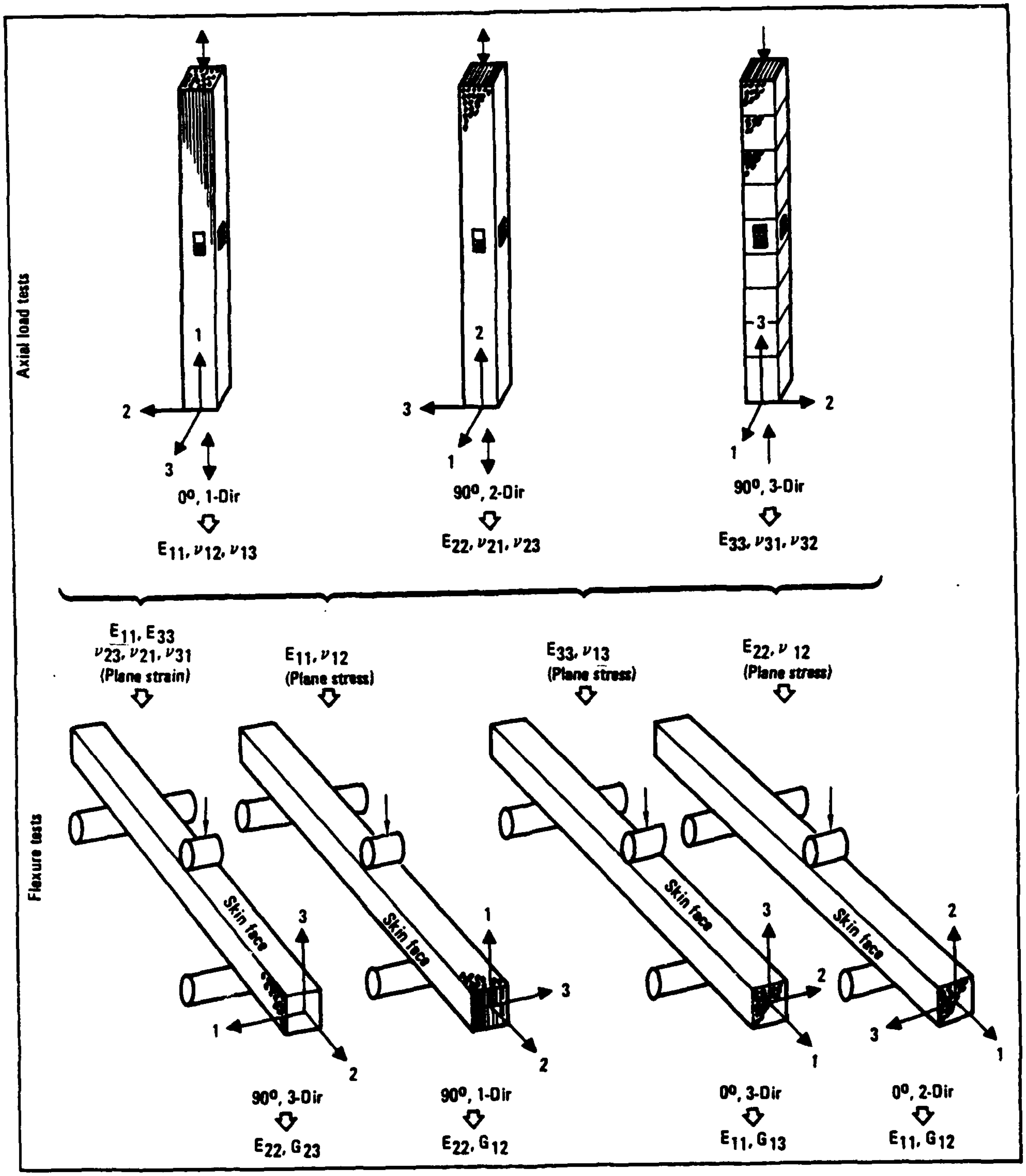

Figure 1. - Test Plan Schematic

Deflection measurements made in the flexure tests included deformation occurring in the test fixture and Hertzian-like bearing deformation of the surface of the beam specimen. These effects comprised an error that was significant for tests at very short span. To provide correctional data, supplementary tests were conducted on specimens loaded as a block in bearing, and on the test fixture with the specimen removed. The correction for bearing deformation was derived from the block-bearing test data with the aid of two additional computer-aided relaxation analyses, by which the Hertzian deformation occurring in the block specimen was related to that occurring in the beam.

Reduction of the flexure test data was achieved by applying the analysis for beam deflection to each test span and condition, using a trial-and-correction procedure to obtain values of the moduli which best fit the multiple test points. The procedure is illustrated by the the flow chart of Figure 2.

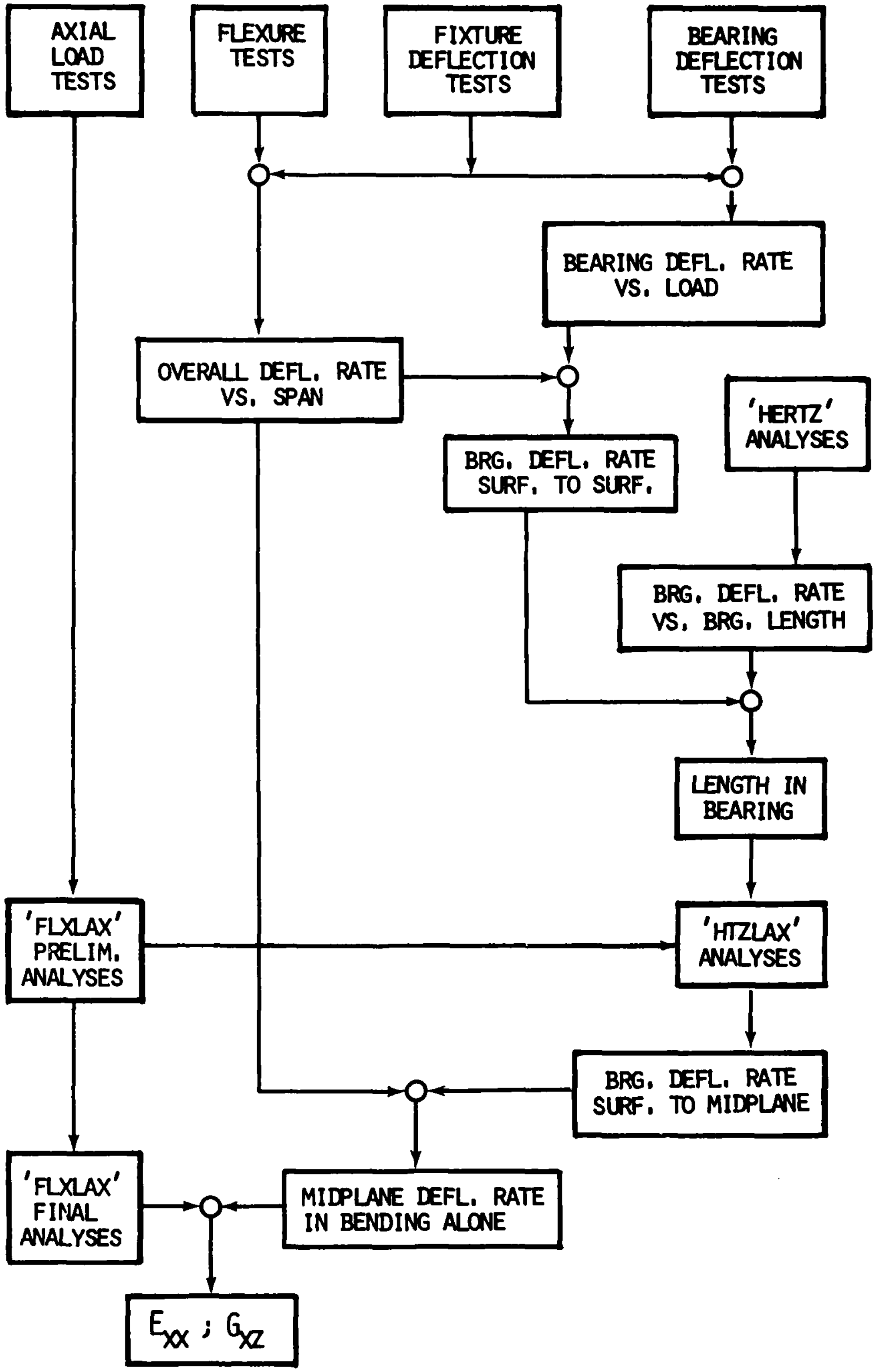

Figure 2 - Flow Chart, Test and Analysis Procedure

SPECIMENS

To furnish stock for test specimens, a 64-ply unidirectional panel was fabricated of T300/5208 low-resin content (35 %) prepreg tape. The layup with symmetrical bleeder plies was placed under vacuum in a press for the standard cure cycle (45 minutes at 132°C followed by 2 hours at 179°C); no post-cure was applied.

To remove resin-rich surface material, a grinding operation using water coolant was performed on both surfaces of the panel. Square specimens of ten-inch length were then cut 0 degrees and 90 degrees to the laminate axis. Final grinding reduced all sections to a uniform 10.59 x 10.59 mm (0.269 x 0.269 inch). Section dimensions were measured to ∓0.0001 inch at stations spaced every inch along the length.

Photomicrography of two specimens after test showed a high degree of homogeneity, although traces of the ply boundaries indicated irregular distortions from the plane. Photomicrographs are presented in the Appendix.

Resin analysis performed per ASTM D3171 on samples taken from the finished specimens indicated a laminate specific gravity of 1.61 and a fiber volume fraction of 68.6 percent. The specimens were dried at 66 °C (150°F) in vacuo for two months prior to test, a procedure estimated to reduce the moisture content to less than 0.1 percent.

Three specimens of each orientation were used for axial tests to obtain extensional properties at 0 degrees and 90 degrees to the fiber direction. The problem of applying test load in the thickness (3) direction was met by cutting short lengths from specimens tested under axial load and reassembling the short sections by adhesive bonding to form 3-tier and 5-tier compression specimens.

Additionally, to obtain specimens for axial load in the 3-direction which were geometrically similar to the others, cubical elements were cut from a fourth 90-degree specimen, reoriented through 90 degrees, and bond-assembled as indicated in Figure 1. These assembled specimens were intended for test under axial tension, but bond failure prevented tension loading of useful magnitude. One of these specimens, which incorporated seventeen cubical elements, was salvaged for axial compression testing by squaring the ends.

Three additional specimens each, of 0° and 90° orientation, were selected for flexure tests. When supported for beam tests the central load was always applied at the specimen midstation, with excess specimen length extending symmetrically beyond the beam supports. Maxiumum variation in measured section dimensions over the test span for any of these specimens was less than 0.3 percent.

EXPERIMENTAL PROCEDURE

Axial Tests

Axial test specimens were instrumented with tee foil gages centrally mounted on all four faces and tested in a universal testing machine. Gage output vs. load data were automatically recorded and reduced with the Rye Canyon centralized digital data acquisition system, which has a demonstrated overall accuracy better than 0.05% of selected range. Tension loading not exceeding 0.003 strain was first applied using Templin-type mechanical grips. The specimens were then reduced to approximately 10 cm (4 inch) length, the ends squared, and compression loads applied between flat, adjustable platens. In compression tests of built-up specimens in the thickness (3) direction, the element bearing the gages was always the central member of a stack of identical and identically oriented elements, in order to minimize end effects.

Representative stress-strain curves obtained in these tests are presented in the Appendix.

Flexural Tests

Flexural tests were conducted in the special fixture shown in Figure 3. Load was applied and reacted through hard steel surfaces of 3.175 mm (0.125 inch) radius. The width of the loading nose matched that of the specimen. Deflection was measured between the loading nose and the fixture base with a clip gage (MTS 632.02B01). The Rye Canyon centralized digital data system was used to acquire, record, and reduce load-deflec ion data. End-to-end calibration of the deflection measurement and recording system against a certified Templin extensometer calibrator indicated overall accuracy and linearity of $\pm$ 1.3 micrometer (0.00005 inch) maximum deviation over a range of 2.5 mm (0.10 inch).

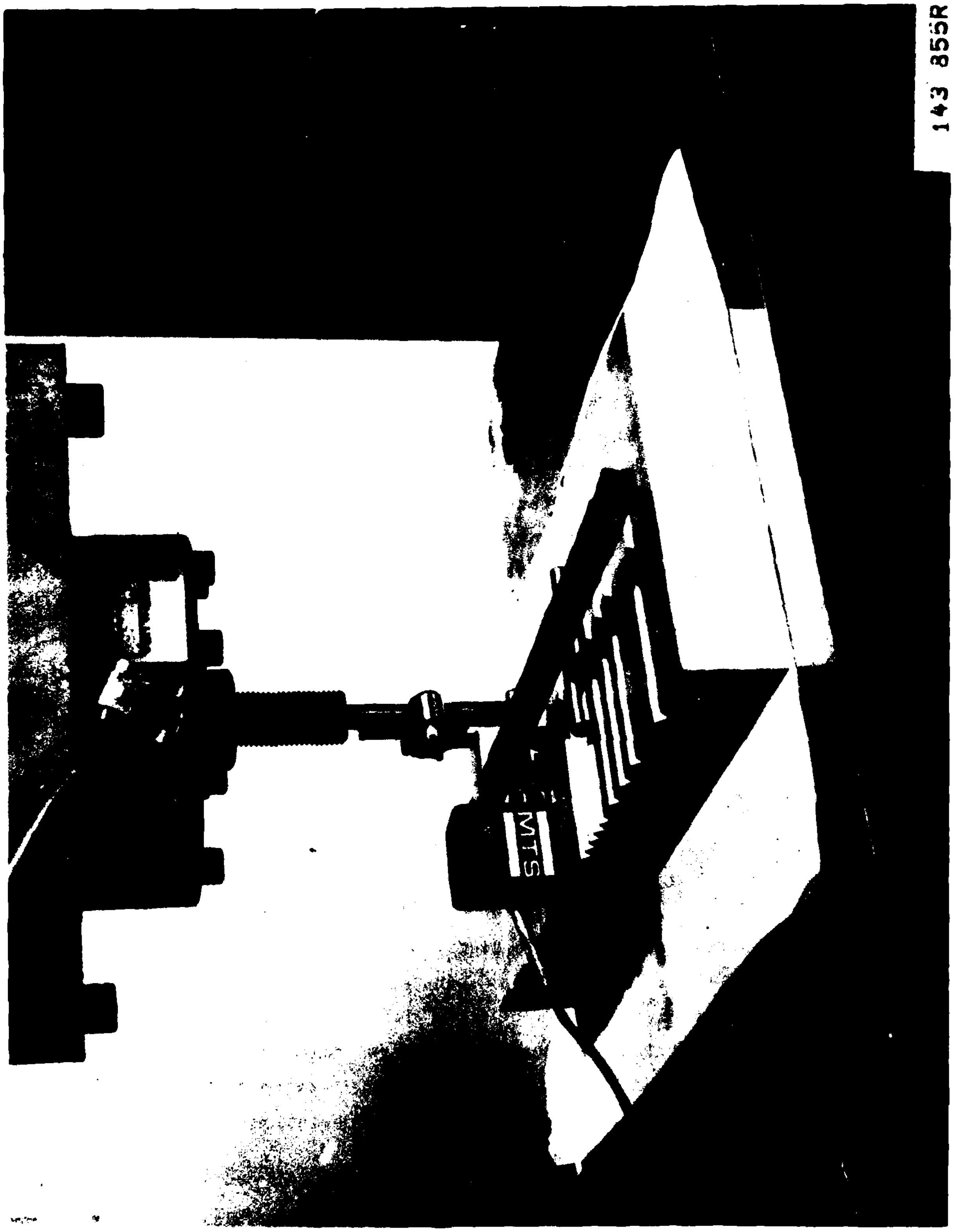

Figure 3 - Flexure Test Specimen in Test Fixture

Tests were conducted at eight different spans on each specimen, providing replicate data from three specimens for each of the four beam orientations. Test span lengths had to be short enough so that shear deformation was large compared with the expected error in measurement, yet not so short that the error caused by local bearing deformation became intolerable. Maximum applied loading corresponded to a beam theory strain Mc/EI of about 0.004. Representative deflection vs. load curves obtained in these tests are reproduced in the Appendix. Except for initial softness, which may be attributed to bearing on asperities and possibly to slight accommodation in torsion, load-deflection relations were quite linear.

The measured load vs. deflection included load carried by the clip gage as well as that on the test specimen. A test was conducted on the clip gage alone, measuring deflection with a dial gage, to evaluate this quantity. The results, which are included in the Appendix, provide a correction which was important for the longest test spans.

A supplementary test was performed to evaluate the error introduced into the flexure test data by deformations which occurred in components of the test fixture included between the gage points. For this test the loading nose was brought into contact with the base of the fixture, and the load-deflection characteristics recorded as before. The resulting curve is reproduced in the Appendix. (These measurements provided only an approximation to the behavior in the flexure test because some deformation occurred in the base under the loading nose instead of at the beam supports).

Tests were also conducted with load applied to representative specimens as in the flexure tests but with the specimens resting directly on the flat base of the test fixture, in order measure specimen bearing deformation. Deflection vs. load curves obtained in these tests are included in the Appendix.

TEST RESULTS AND ANALYSIS

Axial Tests

Compliance data under axial stress were derived by manually evaluating the slopes of the stress-strain curves furnished by the data processing system. This is an operation that produces repeatable values within one half to one percent if the slopes are truly linear. Linearity existed over the major portion of the curve for all tests except those for tension in the fiber direction, in which stiffness increased slightly with load. In these cases secant data were obtained over several ranges.

Corrections for strain gage transverse sensitivity were applied after evaluation of the slopes. Tabulations of the material compliance coefficients, obtained by averaging data from back-to-back strain gages, are recorded in the Appendix. Mean values and coefficients of variation are presented in Table 1.

With only moderate exception, these data are self-consistent and fit the usually assumed model which displays symmetric coupling effects ($S_{12} = S_{21}$, $S_{13} = S_{31}$, $S_{23} = S_{32}$) and transverse isotropy ($S_{22} = S_{33}$, $S_{12} = S_{13}$). A set of coefficients for this model, obtained by averaging all determinations bearing on any particular value, is as follows (units of µe/MPa (µe/psi)):

$$
\begin{array}{c} S_{ij} = \\ i,j = 1,2,3 \end{array}
\left|\begin{array}{ccc}
6.92\ (0.048) & -2.2\ (0.015) & -2.2\ (0.015) \\
-2.2\ (0.015) & 94\ (0.65) & -46\ (0.32) \\
-2.2\ (0.015) & -46\ (0.32) & 94\ (0.65)
\end{array}\right|
$$

Corresponding values of the engineeering constants are listed in Table 2.

TABLE 1 SUMMARY OF COMPLIANCE COEFFICIENTS FROM AXIAL TESTS

TEST LOAD DIRECTION	PROPERTY	TENSION TESTS				COMPRESSION TESTS			
		STRESS RANGE MPa (ksi)	N	MEAN με/MPa (με/psi)	C.V. %	STRESS RANGE MPa (ksi)	N	MEAN με/MPa (με/psi)	C.V. %
Parallel to fiber (1-dir)	S_{11}	70–280(10–40)	8	6.69 (0.0461)	1.4	5–80 (1–11)	6	7.15 (0.0493)	1.6
	S_{21}	70–280(10–40)	4	– 2.18 (–0.0150)	2.7	5–80 (1–11)	3	– 2.19 (–0.0151)	3.6
	S_{31}	70–280(10–40)	4	– 2.13 (–0.0147)	3.0	5–80 (1–11)	3	– 2.15 (–0.0148)	6.6
In-plane trans. (2-dir)	S_{22}	0–40 (0–6)	8	93.3 (0.643)	1.2	5–20 (1–3)	6	91.1 (0.628)	1.9
	S_{12}	0–40 (0–6)	4	– 2.26 (–0.0156)	1.8	5–20 (1–3)	3	– 2.12 (–0.0146)	5.9
	S_{32}	0–40 (0–6)	4	–44.5 (–0.307)	0.7	5–20 (1–3)	3	–43.1 (–0.297)	1.8
Thickness dir. (3-dir)	S_{33}	–	0	–	–	5–130 (1–19)	9	97.4 (0.671)	1.4
	S_{13}	–	0	–	–	5–130 (1–19)	4	– 2.42 (–0.0167)	7.2
	S_{23}	–	0	–	–	5–130 (1–19)	5	–50.2 (–0.346)	4.3

TABLE 2 RESULTS OF AXIAL LOAD TESTS

	n	Value	Coef Var'n %
Extensional Moduli:			
E_{11}	14	21.0 Msi	2.1
E_{22}, E_{33}	27	1.54 Msi	2.9
Poisson's Ratios:			
ν_{12}, ν_{13}	14	0.31	3.8
ν_{23}, ν_{32}	13	0.49	7.3
ν_{21}, ν_{31} (= $\nu_{12}E_{22}/E_{11}$)	13	0.023	8.8

Flexure Tests

Recorded test results were provided by computer in the form of load-deflection curves, which were analyzed manually to obtain values of slope. The resultant deflection rate data (μ in./lb) and the corresponding range of loading over which the behavior was essentially linear are listed in Table 3.

The correctional data also were reduced to terms of deflection rate. The correction for clip gage load was incorporated by combining it with the average deflection rate obtained from the three specimens tested under each of the thirty-two test conditions. These results are included in Table 3. Bearing deformation effects were non-linear in nature, and reduction of the data produced the deflection rate vs. load relations presented in Figure 4. A preliminary analysis of the flexure test data was required before the correction for bearing deformation could be applied.

The finite difference relaxation technique of Reference 19, which was used in analyzing the flexure test data, is based on the stress function relation for orthotropic material:

$$K_z \frac{\partial^4 \phi}{\partial x^4} + 2 \frac{\partial^4 \phi}{\partial x^2 \partial z^2} + K_x \frac{\partial^4 \phi}{\partial z^4} = 0 \tag{1}$$

Here, for plane strain,

$$K_x = \frac{(1-\nu_{xy}^2 E_{yy}/E_{xx})}{E_{xx}/2G_{xz} - \nu_{xz} - \nu_{xy}\nu_{zy} E_{yy}/E_{zz}} \tag{2}$$

$$K_z = K_x \frac{E_{xx}(1 - \nu_{zy}^2 E_{yy}/E_{zz})}{E_{zz}(1 - \nu_{xy}^2 E_{yy}/E_{xx})} \tag{3}$$

Plane stress is expressed by placing $E_{yy} = 0$.

TABLE 3. RESULTS OF BENDING TESTS

FLEXURE TEST DATA							BEARING DEFL. RATES (μ IN./LB)						BEARING CORR. (FIG. 5)			NET DEFL. RATE
			DEFL. RATE ω' (μ in./lb)				AT MEDIAN LOAD			AT MEDIAN LOAD/2			SURF. TO ℄			
BEAM ORIENTATION	SPAN L (IN.)	LOAD RANGE (LB)	NO. 4	NO. 5	NO. 6	CORRECTED AVERAGE*	OVERALL	Ⓐ FIXTURE ALONE	Ⓑ NET IN SPECIMEN	OVERALL	FIXTURE ALONE	Ⓒ NET IN SPECIMEN	AT CENTER	AT SUPP'T	TOTAL $\bar{A}+\bar{B}+\bar{C}/2$	TEST DATA REDUCED (μ IN./LB)
0° 3-dir	1.020	200-600	13.3	13.4	-	13.4	~5.3	~1.5	~3.9	5.9	1.8	4.1	~1.7	~1.8	~5	~8
	1.520	150-400	21.4	21.6	-	21.5	5.6	1.6	4.0	6.1	2.0	4.1	~1.5	~1.6	~4	~17
	2.024	80-220	34.6	34.7	34.1	34.5	6.0	2.0	4.0	7.0	2.4	4.6	1.3	2	4	31
	2.520	50-200	55.0	55.0	55.0	55.1	6.2	2.1	4.1	7.3	2.4	4.9	1.4	2.2	4.6	50.5
	3.020	50-150	82.5	84.0	83.6	83.6	6.6	2.2	4.4	7.9	2.5	5.4	1.5	2.6	5.0	78.6
	4.020	40-130	170	172	173	173	6.8	2.3	4.5	8.3	2.6	5.7	1.6	2.9	5.4	168
	5.017	30-120	312	313	317	317	7.0	2.3	4.7	9	2.7	6	1.7	3	6	311
	6.020	20-80	520	525	521	530	7.9	2.6	5.3	~10	2.9	~7	2.3	4	~7	523
0° 2-dir	1.020	200-600	13.4	13.4	-	13.4	~5.3	~1.5	~3.9	5.9	1.8	4.1	~1.7	~1.8	~5	~8
	1.520	150-400	22.8	21.3	-	22.1	5.6	1.6	4.0	6.1	2.0	4.1	~1.5	~1.6	~4	~18
	2.024	80-220	34.6	35.0	34.3	34.7	6.0	2.0	4.0	7.0	2.4	4.6	1.3	2	4	31
	2.520	50-200	55.5	55.5	54.4	55.1	6.2	2.1	4.1	7.3	2.4	4.9	1.4	2.2	4.6	50.5
	3.020	50-150	84.0	84.3	81.0	83.3	6.6	2.2	4.4	7.9	2.5	5.4	1.5	2.6	5.0	78.4
	4.020	40-130	171	171	174	173	6.8	2.3	4.5	8.3	2.6	5.7	1.6	2.9	5.4	168
	5.017	30-120	313	314	315	317	7.0	2.3	4.7	9	2.7	6	1.7	3	6	311
	6.020	20-80	520	528	524	532	7.9	2.6	5.3	~10	2.9	~7	2.3	4	~7	525
90° 3-dir	1.020	25-75	48.5	47.5	48.4	48.2	9.5	2.6	6.9	~11.4	2.9	~8.5	4.3	4.5	9.2	39.0
	1.520	20-40	126	127	125	126	10.8	2.8	8.0	~13.2	3.6	~9.6	3.8	3.9	8.5	117.5
	2.024	15-35	276	272	272	276	11.4	2.9	8.5	~14.1	3.8	~10.3	3	3	7	269
	2.520	5-25	508	510	515	519	13.4	3.6	~10	~16	5	~11	3	2	8	511
	3.020	5-20	847	857	865	878	15	3.8	~11	~16	6	~10	2	3	7	871
	4.020	3-20	1920	1920	-	2030	~15	4.0	~11	~16	~6	~10	2	3	8	2020
	5.017	0-16	3570	-	-	3980	~15	~5	~12	~17	~7	~10	2	3	9	3970
	6.020	3-13	5700	5670	-	6790	~16	~5	~11	~17	~7	~10	2	3	9	6780
90° 1-dir	1.020	30-70	43.8	42.0	42.8	42.9	3.8	2.6	1.2	5.1	2.9	2.2	0.6	1.3	3.8	39.1
	1.520	20-40	121	117	121	120	4.7	2.8	1.9	~6.5	3.6	~2.9	1.2	~1.6	4.7	115.3
	2.024	10-40	272	266	271	272	5.1	2.9	2.2	~6.8	3.9	~2.9	1.4	1.6	5.1	267
	2.520	5-25	513	505	508	516	~7	3.6	~3	~8	~5	~3	2	1.6	6.4	510
	3.020	5-20	857	837	855	871	~7	3.8	~3	~8	~6	~2	2	1	6	865
	4.020	4-20	1940	1920	-	2040	~7	4	~3	~8	~6	~2	2	1	7	2030
	5.017	2-16	3610	3610	-	4030	~8	~5	~3	~9	~7	~2	2	1	8	4020
	6.020	2-13	5700	5680	-	6800	~8	~5	~3	~9	~7	~2	2	1	8	6790

*$\omega'_{clip\ gage}$ = 34910 μ in./lb; $\omega'_{corrected} = 1\Big/\left(\frac{1}{\omega'_{meas}} - \frac{1}{34910}\right)$

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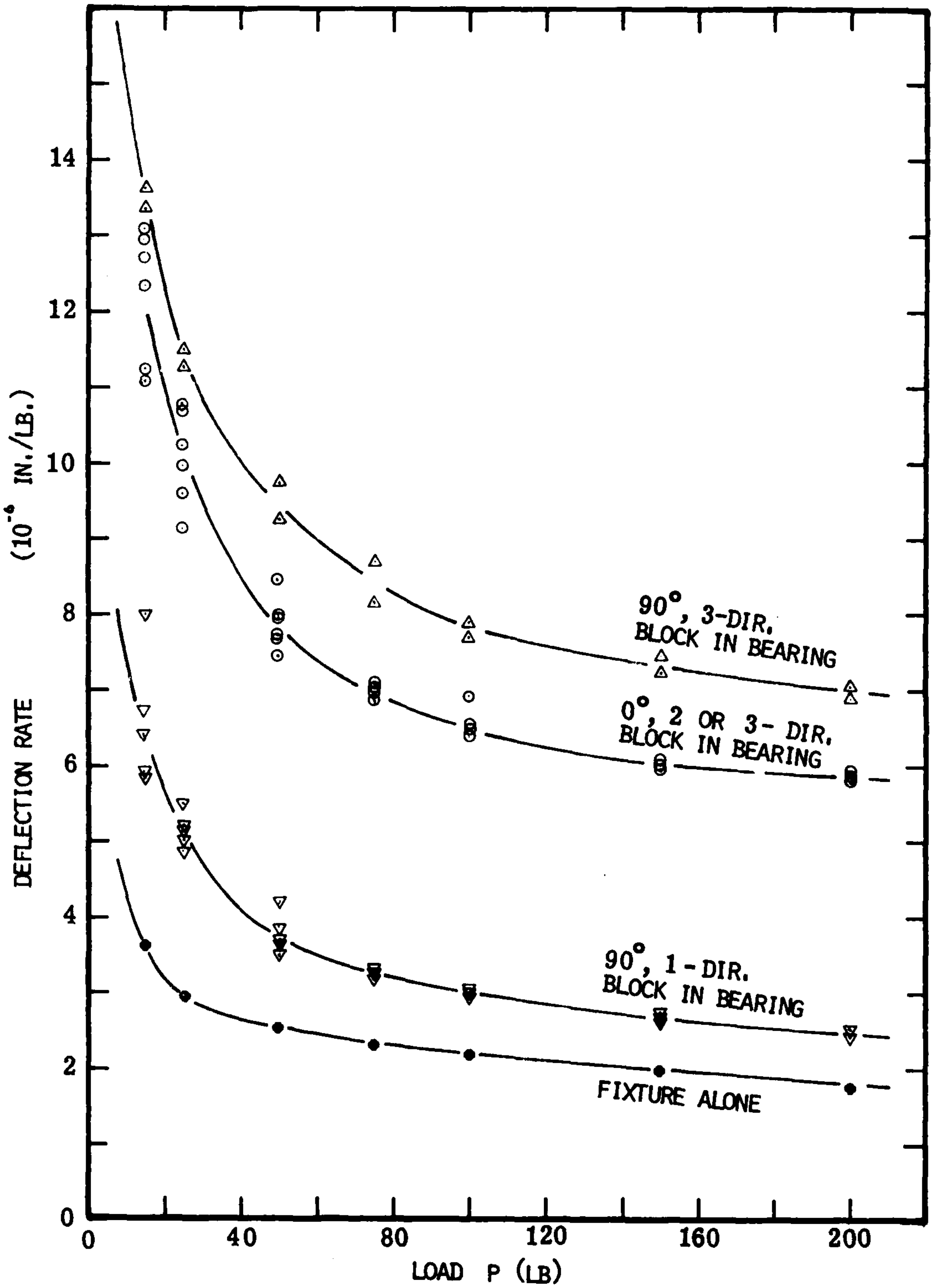

Figure 4 - Experimental Deflection Rates (Slopes of Recorded Load - Deflection Curves)

The stress function solution was applied to treat the central portion of the test specimen out to a distance 2h (twice the beam depth) from the point of load application. Deflection of the remainder of the span was calculated by beam theory. The net of point values was spaced h/10 in the spanwise (x) direction and h/20 in the depth (z) direction. The model is shown schematically in Figure 5. Preliminary studies showed that this analysis provided the desired precision in deflection calculation.

Preliminary solutions of the stress function matrix were derived for each of the flexure test conditions, using elastic constants determined in the axial tests and assuming values of the shear moduli. The case of beam load in the 2-3 plane (obtained in the 90-degree beam with fibers oriented transverse to the load) was analyzed as plane strain, the others as plane stress. Best-fit values of E_{xx} and G_{xz} were then derived by placing

$$(dw_{test}/dP)_i = a\,(dw_b/dP)_i + b(dw_s/dP)_i \qquad (4)$$

Here dw_b/dP and dw_s/dP are deflection rates attributable to bending stress and to shearing stress, respectively, calculated at the beam midplane; a and b are error factors. Defining, for simplification,

$$x = \frac{dw_s/dP}{dw_b/dP} \quad ; \qquad y = \frac{dw_{test}/dP}{dw_b/dP} \qquad (5)$$

Then

$$y_i = a + bx_i \qquad (6)$$

and a and b may be derived by linear regression of y on x. If bending and shear deformation are assumed to occur independently of each other, a and b become correction factors for the moduli E_{xx} and G_{xz}. The error in this asssumption becomes negligible if the correction is small, making iterative improvement of the relaxation solution a practical measure.

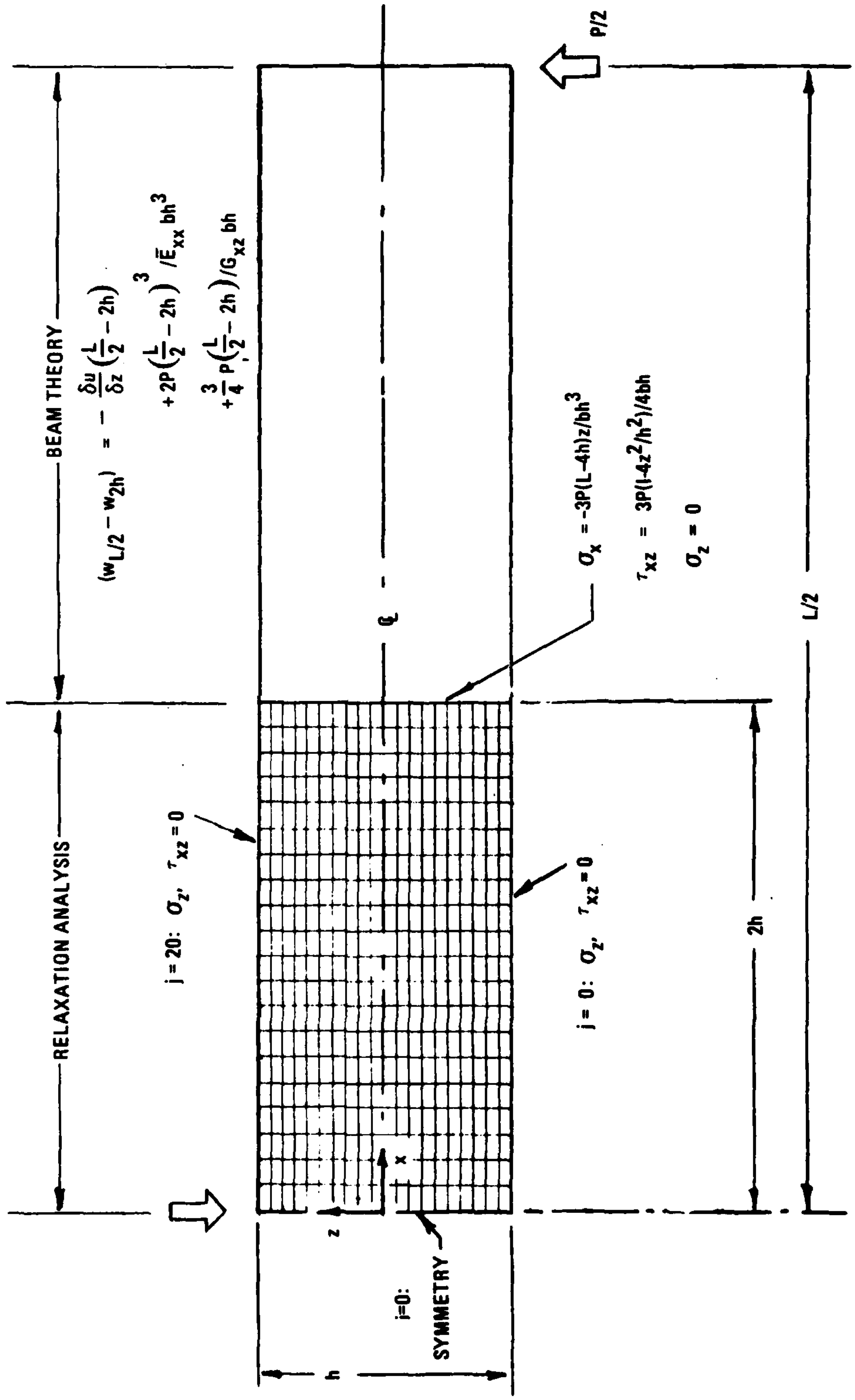

Figure 5. - Model Used in Computer Program 'FLXLAX'

Correction of the flexure test data was then made for bearing deformations occurring between the surface at which load was applied and the midplane of the beam. Analysis was required to derive this correction quantity from measurements taken surface-to-surface on a block which carried no bending stress. General solutions for the two cases (viz., block in bearing supported at the opposite surface, and section of a beam supported by moment and shear at the ends) were obtained by extensions of the stress function relaxation analysis described above which used closer grid spacing. For each of the flexure test conditions, a set of specific solutions for deformation under the two support conditions was derived for a range of values of the width over which the central load was distributed. The block-bearing test data could then be used to evaluate a load distribution parameter for each condition. By assuming this parameter applied also to the beam-supported bearing problem, the applicable solution was identified and the bearing deformation occurring between the loading nose and the beam midplane was evaluated.

This analytic procedure is considered only an approximation, which is especially limited for short spans and high loads, but adequate as a correction procedure. To facilitate the correction process, the analytic solutions are arranged in nomographic fashion in Figure 6. Entry to the lower set of curves with the block-bearing deflection rate, obtained from Figure 4 at the median of the load range of interest, lead via the upper curves to the surface-to-midplane deflection rate in the flexure test. Data derived by this method for the loading station, and (under half the beam load) for the support station. were applied to correct the flexure data in Table 3. Also included in Table 3 are corrections for deflection occurring in the fixture, taken from Figure 4.

With the flexure test data refined, additional iterations of the solution for E_{xx} and G_{xz} were performed until best-fit values to the eight test points of each set were obtained. Variation in the Poisson's ratios from the values determined in the extensional tests was not investigated, other than to

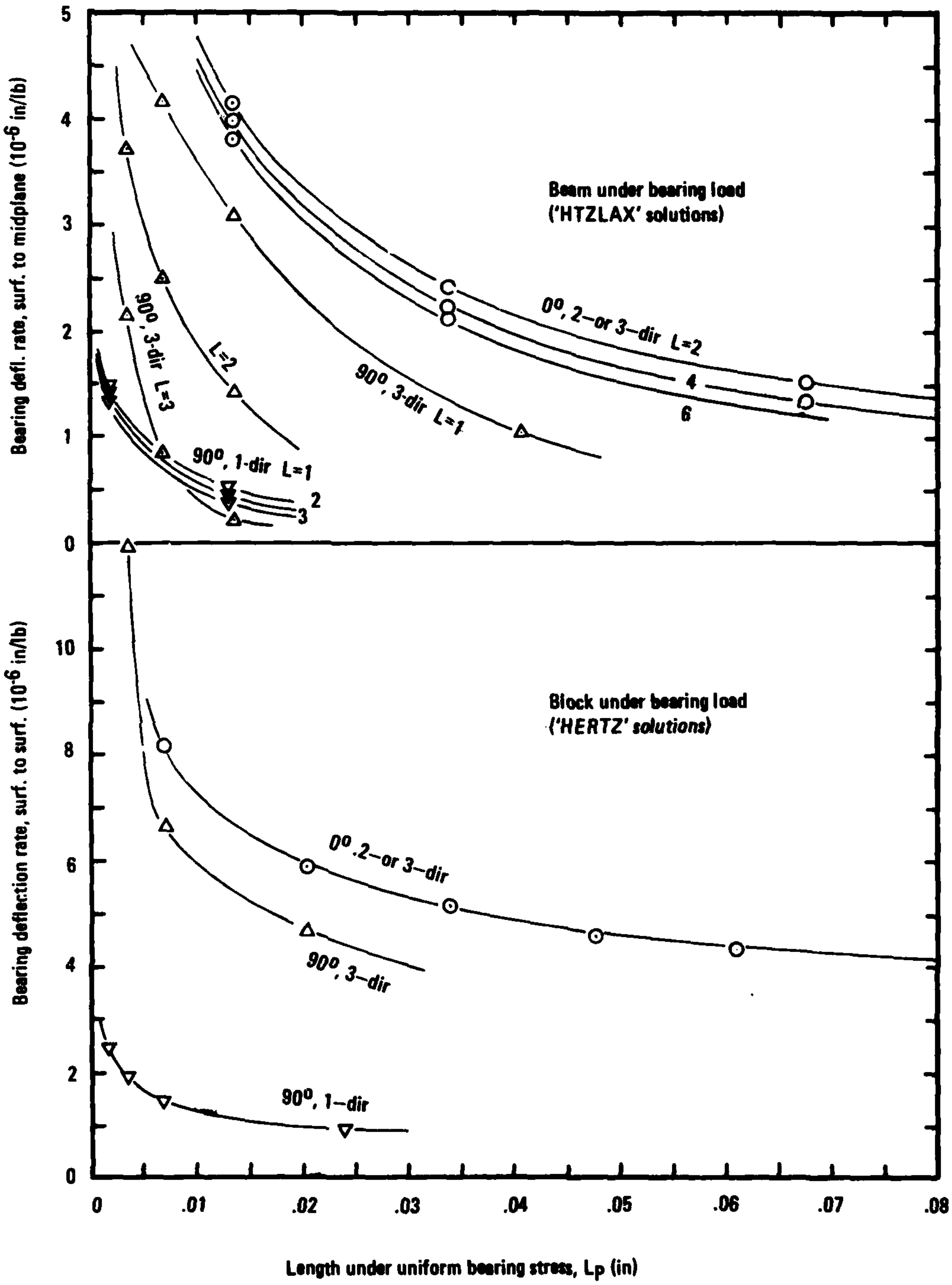

Figure 6. - Nomograph for Converting Block Bearing Deflection Data to Surface-to-Midplane Bearing Deflection of Beam

demonstrate the effect to be too small to utilize. The results, which provide at least one and in some cases two determinations of the extensional and the shear moduli, are presented in Table 4 and summarized in Table 5. Extensional and shear moduli derived from beams of different fiber orientation are seen to be in good agreement, and agreement of the two transverse shear moduli G_{12} and G_{13} (from 0° and 90° beams, respectively) again confirms the material as being transversely isotropic. Furthermore, the transverse shear modulus G_{23} is in almost exact agreement with the value expected by transverse isotropy, namely, $G_{23} = E_{22}/2(1+ \nu_{23})$ or .52 Msi.

The fit to the test data achieved by iterative refinement of the relaxation solution is indicated in Figure 7. While this plot demonstrates that the computation provides an exceptionally good representation of total beam deflection, it is misleading with regard to the precision of the shear modulus determination. This process is better characterized by the plot of final values of the deflection rate ratios presented in Figure 8.

TABLE 4. ANALYSIS OF FLEXURE DATA

	Test Results				Relaxation Solutions				Best Fit Analysis		
Beam Orient.	Depth	Width	Span	w'(tst)	Assumptions	w'b	w's	w'(tot)	X(i)	Y(i)	
0-deg,3-dir	0.2695	0.2691	1.020	8		1.24	6.81	8.0	5.5135	6.4767	
0-deg,3-dir	0.2695	0.2691	1.520	17	Plane Stress	6.00	10.79	16.8	1.7986	2.8330	r=0.9999
0-deg,3-dir	0.2695	0.2691	2.024	31	Exx=21.2 Msi	15.91	14.80	30.7	0.9306	1.9487	a=0.9973
0-deg,3-dir	0.2695	0.2691	2.520	50.5	Ezz=1.55 Msi	32.24	18.74	51.0	0.5812	1.5665	b=0.9965
0-deg,3-dir	0.2695	0.2691	3.020	78.6	Gxz=0.65 Msi	57.28	22.71	80.0	0.3964	1.3721	E11=21.26
0-deg,3-dir	0.2695	0.2691	4.020	168	Vxz=0.31	139.88	30.69	170.6	0.2194	1.2010	G13=0.652
0-deg,3-dir	0.2695	0.2691	5.017	311		276.48	38.64	315.1	0.1398	1.1249	
0-deg,3-dir	0.2695	0.2691	6.005	523		476.03	46.44	522.5	0.0976	1.0987	
0-deg,2-dir	0.2691	0.2695	1.020	8		1.24	6.81	8.1	5.4850	6.4438	
0-deg,2-dir	0.2691	0.2695	1.520	18	Plane Stress	6.04	10.79	16.8	1.7852	2.9777	r=0.9991
0-deg,2-dir	0.2691	0.2695	2.024	31	Exx=21.1 Msi	16.03	14.80	30.7	0.9306	1.9487	a=1.0068
0-deg,2-dir	0.2691	0.2695	2.520	50.5	Ezz=1.55 Msi	32.46	18.73	51.2	0.5771	1.5557	b=1.0010
0-deg,2-dir	0.2691	0.2695	3.020	78.4	Gxz=0.65 Msi	57.67	22.71	80.4	0.3937	1.3594	E11=20.96
0-deg,2-dir	0.2691	0.2695	4.020	168	Vxz=).31	140.90	30.69	171.6	0.2178	1.1924	G12=0.649
0-deg,2-dir	0.2691	0.2695	5.017	311		278.42	38.64	317.1	0.1388	1.1170	
0-deg,2-dir	0.2691	0.2695	6.005	525		479.76	46.44	526.2	0.0968	1.0943	
90-deg,3-dir	0.2695	0.2692	1.020	39.0	Plane Strain	29.30	9.45	38.7	0.3227	1.3313	
90-deg,3-dir	0.2695	0.2692	1.520	117.5	Exx=1.55 Msi	102.49	14.45	116.9	0.1409	1.1464	r=0.9986
90-deg,3-dir	0.2695	0.2692	2.024	269	Eyy=21.0 Msi	246.57	19.47	266.0	0.0790	1.0910	a=1.0151
90-deg,3-dir	0.2695	0.2692	2.520	511	Ezz=1.55 Msi	480.07	24.42	504.5	0.0509	1.0644	b=0.9709
90-deg,3-dir	0.2695	0.2692	3.020	871	Gxz=0.52 Msi	830.77	29.41	860.2	0.0354	1.0484	E22=1.527
90-deg,3-dir	0.2695	0.2692	4.020	2020	Vxz=0.49	1968.82	39.38	2008.2	0.0200	1.0260	G23=0.536
90-deg,3-dir	0.2695	0.2692	5.017	3970	Vxy=0.023	3835.11	49.33	3884.4	0.0129	1.0352	
90-deg,3-dir	0.2695	0.2692	6.005	6780	Vzy=0.023	6585.70	59.19	6644.9	0.0090	1.0295	
90-deg,1-dir	0.2682	0.2695	1.020	39.1		31.39	7.71	39.1	0.2456	1.2456	
90-deg,1-dir	0.2682	0.2695	1.520	115.3	Plane Stress	106.26	11.72	118.0	0.1103	1.0851	r=0.9876
90-deg,1-dir	0.2682	0.2695	2.024	267	Exx=1.55 Msi	253.70	15.75	269.4	0.0621	1.0524	a=0.9990
90-deg,1-dir	0.2682	0.2695	2.520	510	Ezz=21.2 Msi	492.16	19.71	511.9	0.0400	1.0362	b=0.9605
90-deg,1-dir	0.2682	0.2695	3.020	865	Gxz=0.65 Msi	849.14	23.70	872.8	0.0279	1.0187	E22=1.552
90-deg,1-dir	0.2682	0.2695	4.020	2030	Vxz=0.023	2007.98	31.68	2039.7	0.0158	1.0110	G12=0.677
90-deg,1-dir	0.2682	0.2695	5.017	4020		3907.63	39.63	3947.3	0.0101	1.0288	
90-deg,1-dir	0.2682	0.2695	6.005	6790		6704.71	47.52	6752.2	0.0071	1.0127	

Beam dimensions in inches. Deflection rate w'=dw/dP, μin/lb. w'b=bending component, w's=shear component.
Best fit analysis by linear regression of Y on X; X=w's/w'b; Y=w'tst/w'b; Y=a+bX

TABLE 5. SUMMARY OF FLEXURE TEST RESULTS
(Extensional and Shear Moduli in Msi)

Test Condition	0°, 3-dir	0°, 2-dir	90°, 3-dir	90°, 1-dir
N	22	22	20	21
E_{11}	21.26	20.96	–	–
E_{22}	–	–	1.527	1.552
E_{33}	–	–	–	–
G_{12}	–	–	–	0.677
G_{13}	0.652	0.649	–	–
G_{23}	–	–	0.536	–

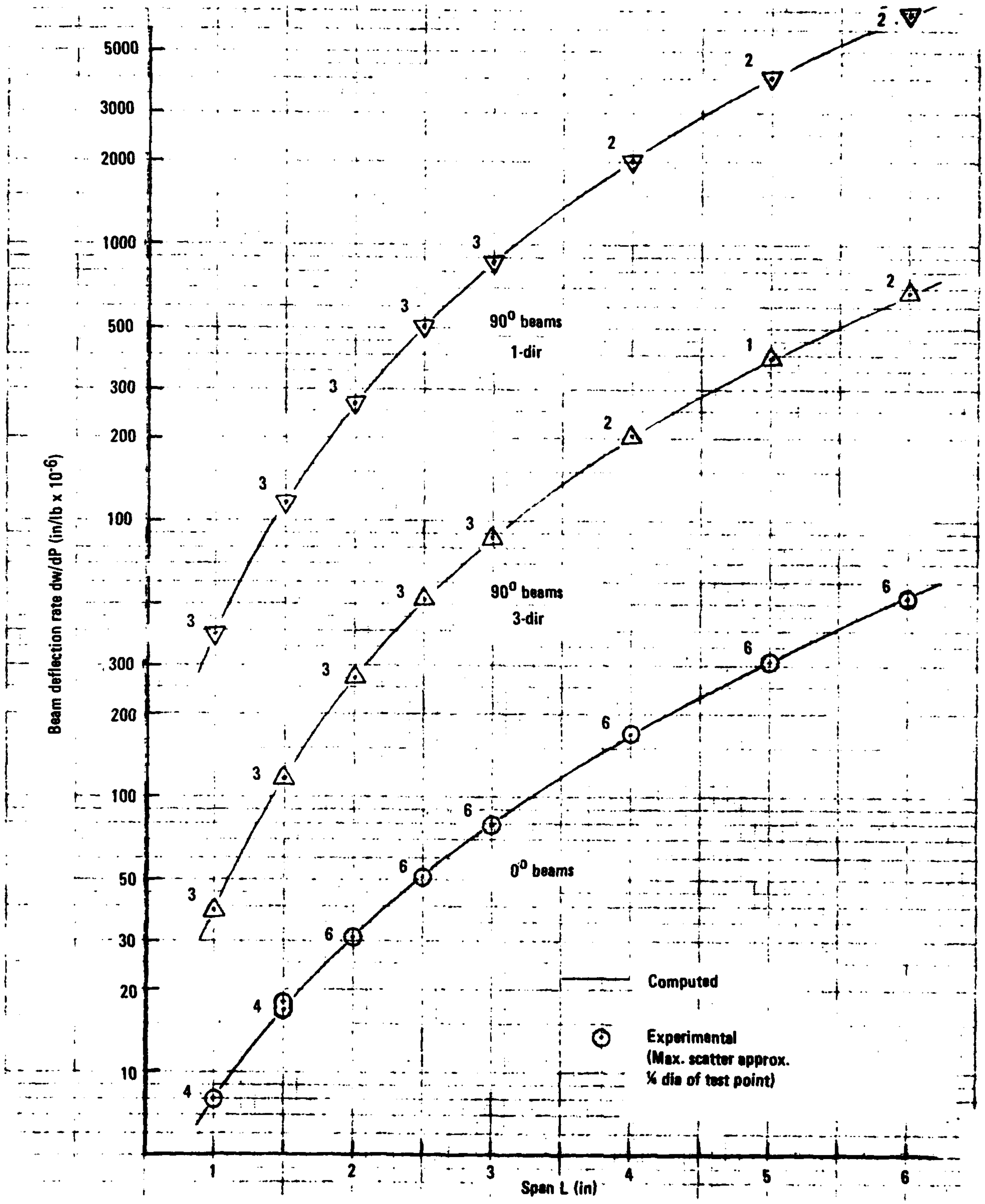

Figure 7. Comparison of Computed Solutions for Beam Deflection with Test Data

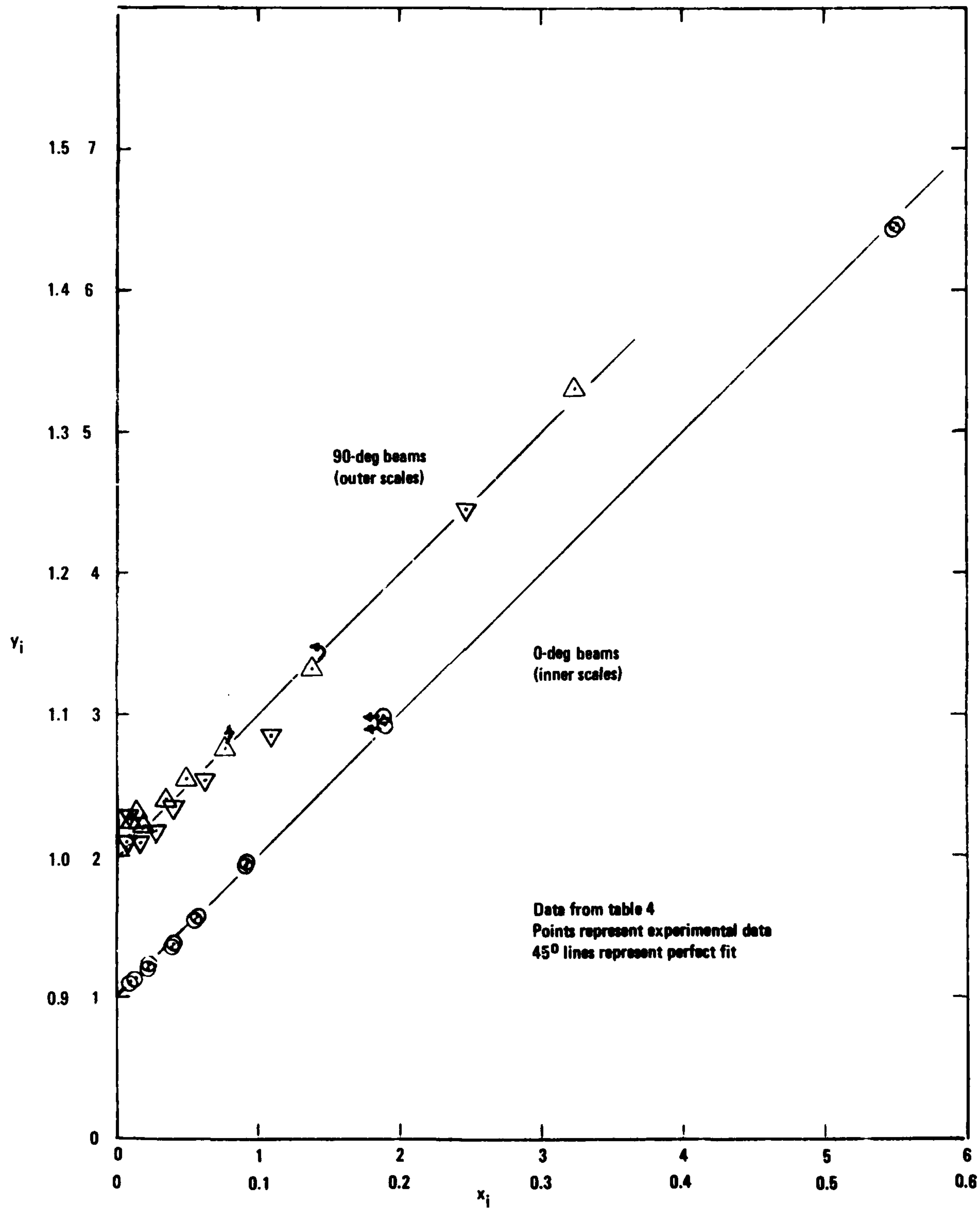

Figure 8. - Deflection Rate Ratios Corresponding to Best Fit Solutions for E_{xx} and G_{xz}

Approximate Method for Shear Calculations

Shear deflection occurring in beams is usually estimated by assigning a value to the Timoshenko shear coefficient K in the relation,

$$w_{total} = \iint \frac{M}{EI} \, dx \, dx + \frac{1}{K} \int \frac{S}{GA} \, dx \tag{7}$$

Here the first term is the Bernoulli-Euler bending deflection found in handbook formulas; it recognizes no restraint of section warping. The second term is a "shear correction" which includes all other effects, presumed to cause a shearing type of deflection. K is generally thought to be a section property that varies only with section shape; various sources cite values ranging from 2/3 to 1.0. Consideration of the shear stress destribution in beams makes it clear that K may vary over the span (Reference 19). Therefore, any value which is to be used outside of the integral as in (7) must be specific not only for load and section but for span.

The results of the current study can be utilized to develop rational values of K. Such data, obtained by introducing the appropriate values from Table 4 into (7) and solving for K, are presented in Figure 9. (For the 90° beams loaded in the 3-direction, the value of E was taken as $E_{22}/(1-\nu_{21}\,\nu_{12})$ in accordance with representation as plane strain.)

Reissner (Reference 20), and Nair and Reissner (Reference 21), working from fundamental energy considerations, have established upper and lower bounds for the shear deflection that occurs in a beam which does not deform locally at the load and support stations. In the 90-degree beam loaded in the 1-direction, the high fiber stiffness produces boundary conditions which are closely represented by Reissner's model, and the resulting values of K, as plotted in Figure 9, are seen to lie close to the prescribed bounds calculated

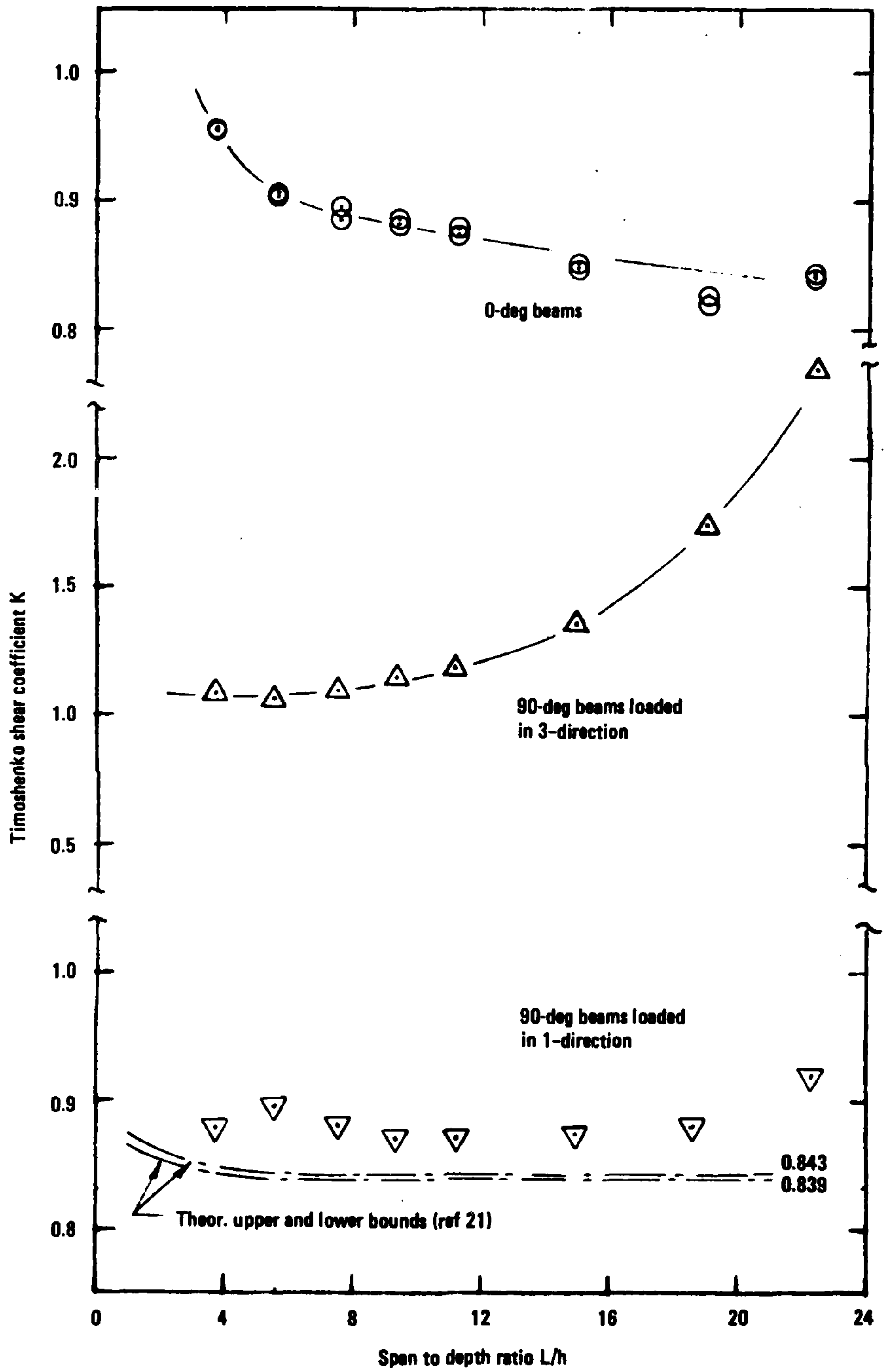

Figure 9. - Variation of the Timoshenko Shear Coefficient with Span and Direction of Load

from Reference 21. When the load is transverse to the fiber, however, local deformation at the loading station is significantly greater, and consequently K for very short spans is increased and may exceed 1.0.

These differences in the value of K are produced by variation in the way shear is introduced into the beam, interacting with section constraint. Shear stress distribution adjacent to the loading station for the 90-degree beam, L = 1.02 inch, loaded in the 3- direction, is contrasted with that for load in the 1- direction in Figure 10 (data from the relaxation solutions). The high peak stress and distorted distribution associated with loading transverse to the fibers tends to produce large section warping. The central section cannot warp, however, and adjustment to this condition reduces overall beam deflection. Thus, short beams with low E_{zz} may appear to be stiffer in "shear" than those for which E_{zz} is large.

Accuracy in the calculation of K is adversely affected by limitations in accuracy of the current set of relaxation solutions. While these data have a precision of better than 0.1 percent, they suffer a small error as a result of the finite dimensions of the grid. Such errors have a greater effect on K than on the shear modulus, because after G_{xz} has been evaluated, the relaxation solution values enter once again in the w_{total} term of Eq. (7), and in this case without the benefit of multiple points. For cases important in design, further investigation is desirable to confirm the results and to establish a broader basis for extrapolation to other materials.

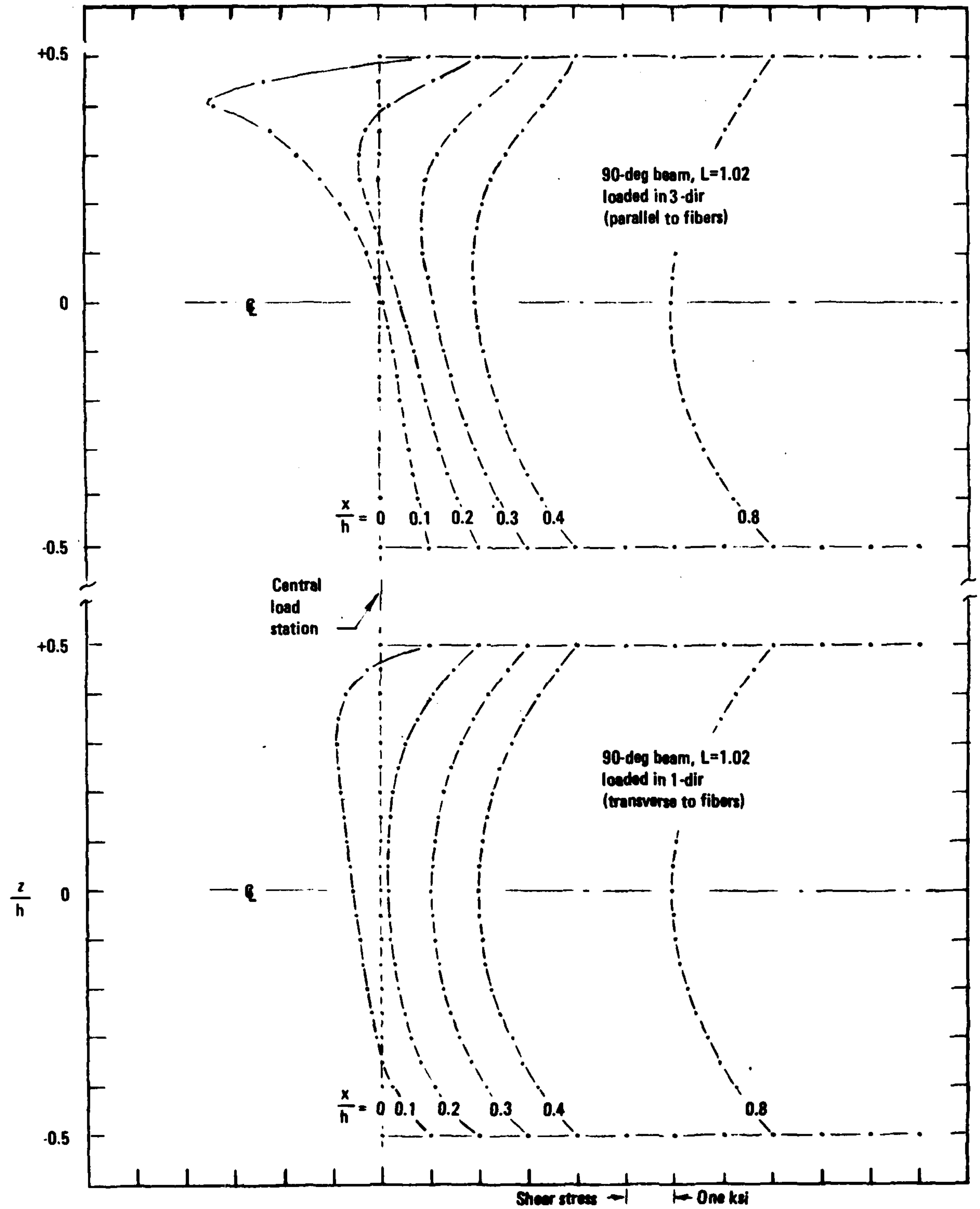

Figure 10. - Calculated Shear Stress Distributions for 90-degreee Beams, L = 1.02-in

Overall

Where data obtained in the axial load tests and the flexure tests overlap, only small differences are seen to exist, and these discrepancies probably represent the accuracy of the test methods. By taking rounded values which are consistent with each other and the indications of transverse isotropy, a complete set of seven ~~the nine~~ elastic constants independently evaluated is obtained and presented in Table 6.

These data represent the overall results of replicate tests and various test conditions. Scatter of test results with different test procedures is no more than a few percent.

These results were derived by assuming linear, orthotropic elasticity, an assumption justified by the structure of the material and the linearity exhibited in the basic load-deflection data. The fact that the final results provide a complete, self-consistent set of properties confirms this model and appears to refute suggestions of non-linear elasticity relations found in the literature (Reference 16 and 17, for example). However, the scope of the current program with regard to stress range and condition is insufficient to resolve this question. For the type of loading and the material tested, simple orthotropy provides a satisfactory model.

TABLE 6 OVERALL SUMMARY

Elastic Constants of T300/5208 Laminate As Tested

PROPERTY	VALUE	
	(GPa)	(Msi)
E_{11}	145.	21.0
E_{22} , E_{33}	10.7	1.55
G_{12} , G_{13}	4.50	0.65
G_{23}	3.70	0.52
ν_{12} , ν_{13}	0.31	
ν_{23} , ν_{32}	0.49	
ν_{21} , ν_{31}	0.023	

CONCLUSIONS

A complete set of the nine elastic constants experimentally determined for a 64-ply T300/5208 unidirectional laminate is presented in Table 6. These data are based on multiple independent experimental determinations, with the overall means of the test values modified slightly to obtain a consistent set.

The results agree with values cited in the literature, except in the case of the in-plane shear modulus G_{12}. The value obtained here (0.65Msi) is somewhat lower than that expected from $\pm 45^\circ$ tension tests (0.80 Msi) and the Pagano torsion test (0.87 Msi), and substantially lower than reported for ultrasonic tests (1.03 Msi).

The results obtained confirm, to the limits of the experiment, that the elastic stress-strain relations are linear and that the material is transversely isotropic.

Calculations of the Timoshenko shear coefficient indicate a substantial variation with the orientation of the orthotropic axes of the beam and with the span. In some cases the calculated values exceed by a considerable amount the recognized bounds for a cantilever which has slightly different end conditions. Boundary conditions are thus seen to have an unexpectedly strong influence on the deformation attributable to shear. Such an effect could explain variations in performance associated with different test procedures, and would increase the problems of analysis and design.

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APPENDIX

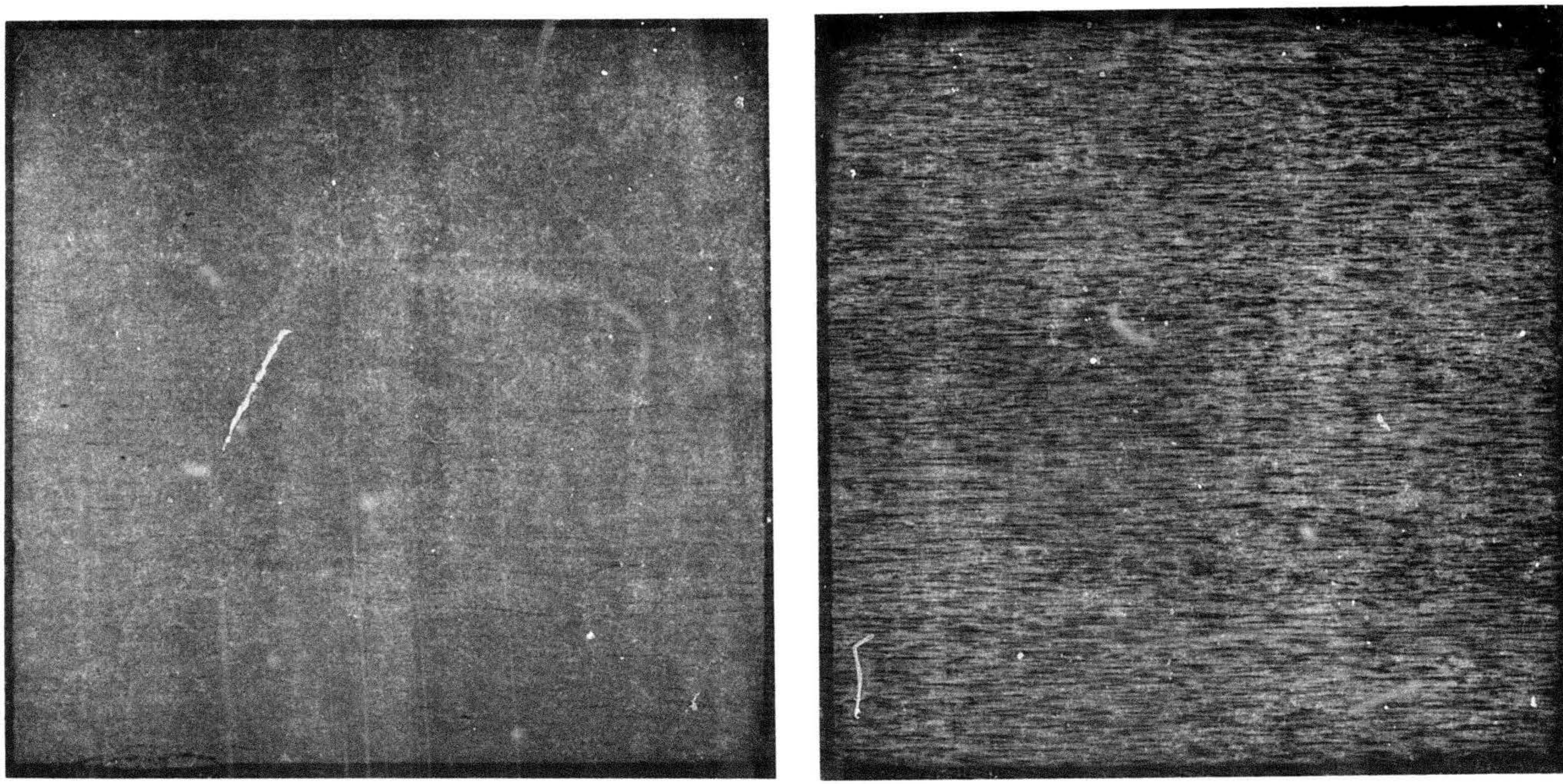
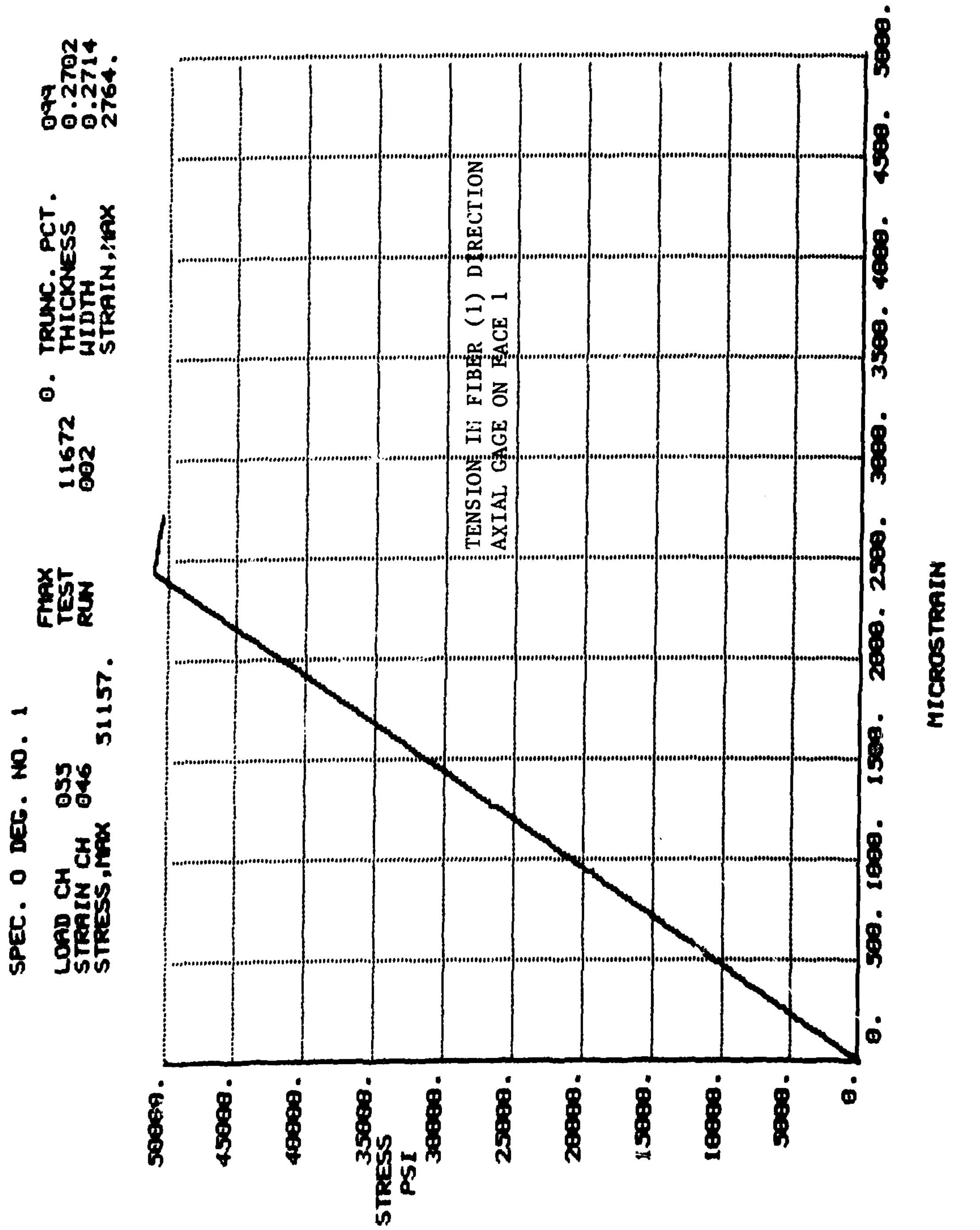
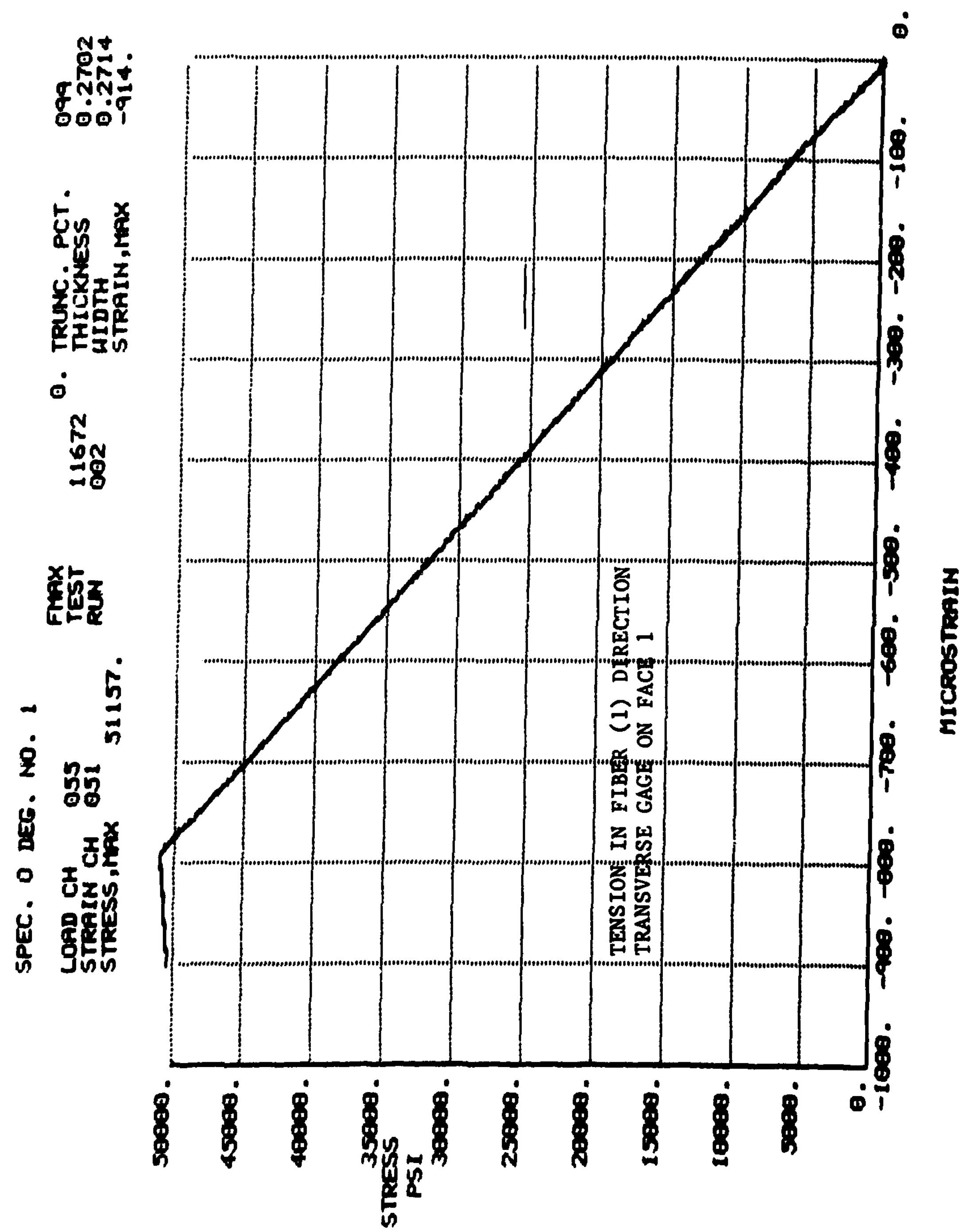


Figure A-1 - Sections of Flexure Test Specimens 0^{o} No. 1 (left) and 90^{o} No. 1 (right), at 15x Magnification. Damage to external surface of 0^{o} specimen was caused by test machine grips.


SPEC. 0 DEG. NO. 1
LOAD CH 055
STRAIN CH 046
STRESS,MAX 51157.
FMAX 11672
TEST 002
RUN 0.
TRUNC. PCT. 099
THICKNESS 0.2702
WIDTH 0.2714
STRAIN,MAX 2764.
TENSION IN FIBER (1) DIRECTION
AXIAL GAGE ON FACE 1
STRESS PSI
50000.
45000.
40000.
35000.
30000.
25000.
20000.
15000.
10000.
5000.
0.
MICROSTRAIN
0.
500.
1000.
1500.
2000.
2500.
3000.
3500.
4000.
4500.
5000.



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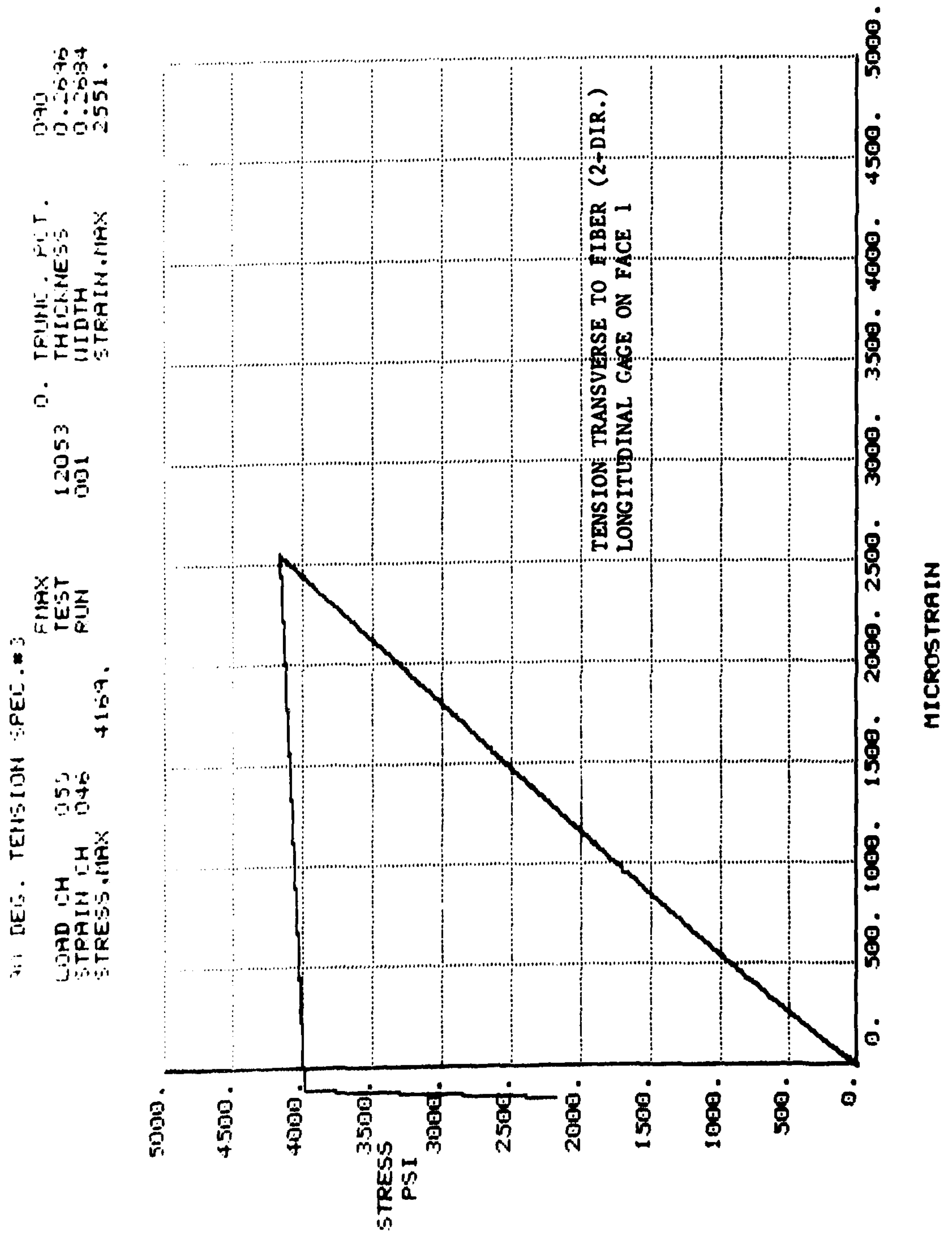
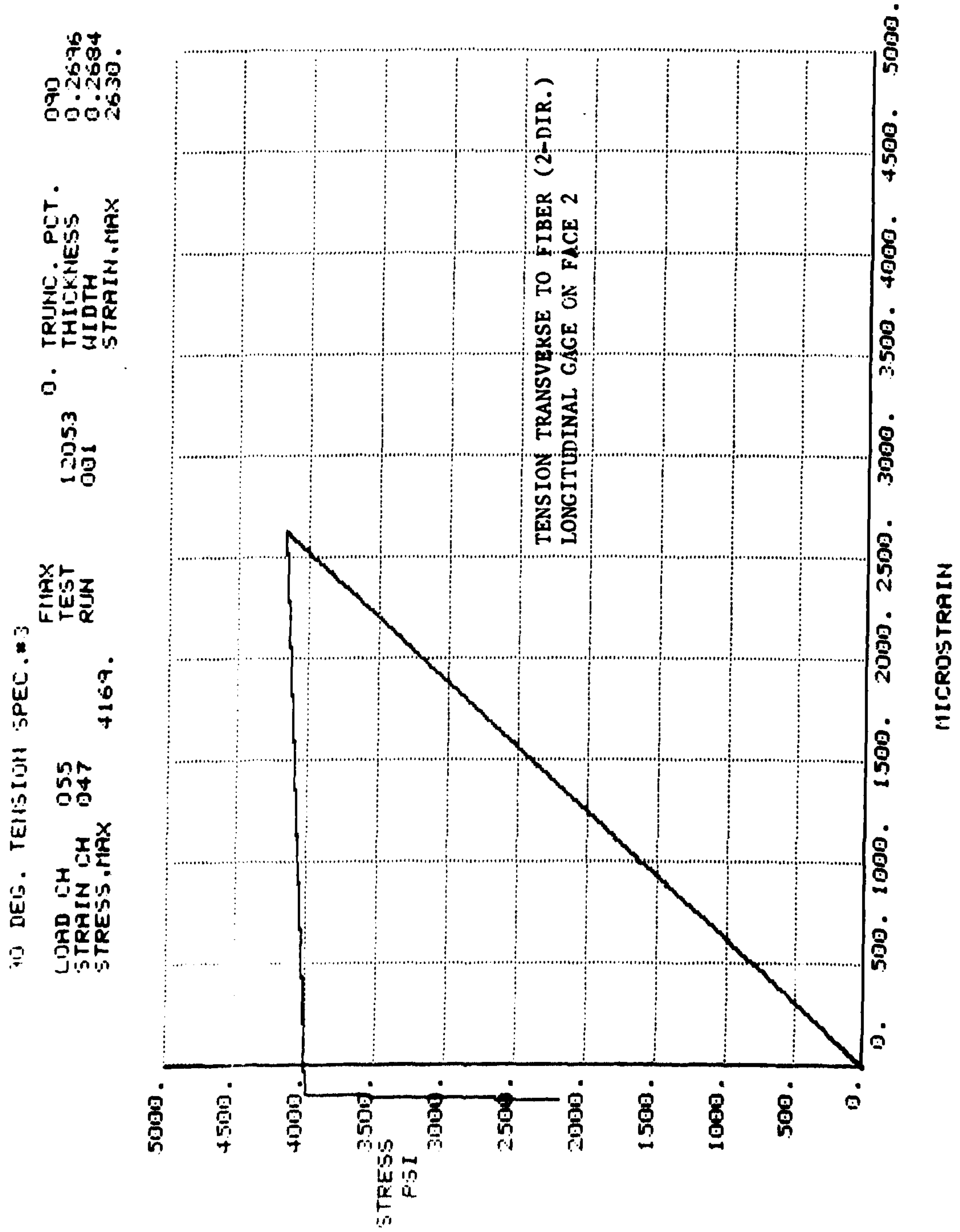

90 DEG. TENSION SPEC.#3
LOAD CH 055
STRAIN CH 046
STRESS.MAX 4169.
FMAX 0.
TEST 12053
RUN 001
TRUNC. PCT. 090
THICKNESS 0.2696
WIDTH 0.2684
STRAIN.MAX 2551.
STRESS PSI
0. 500. 1000. 1500. 2000. 2500. 3000. 3500. 4000. 4500. 5000.
MICROSTRAIN
TENSION TRANSVERSE TO FIBER (2-DIR.)
LONGITUDINAL GAGE ON FACE 1



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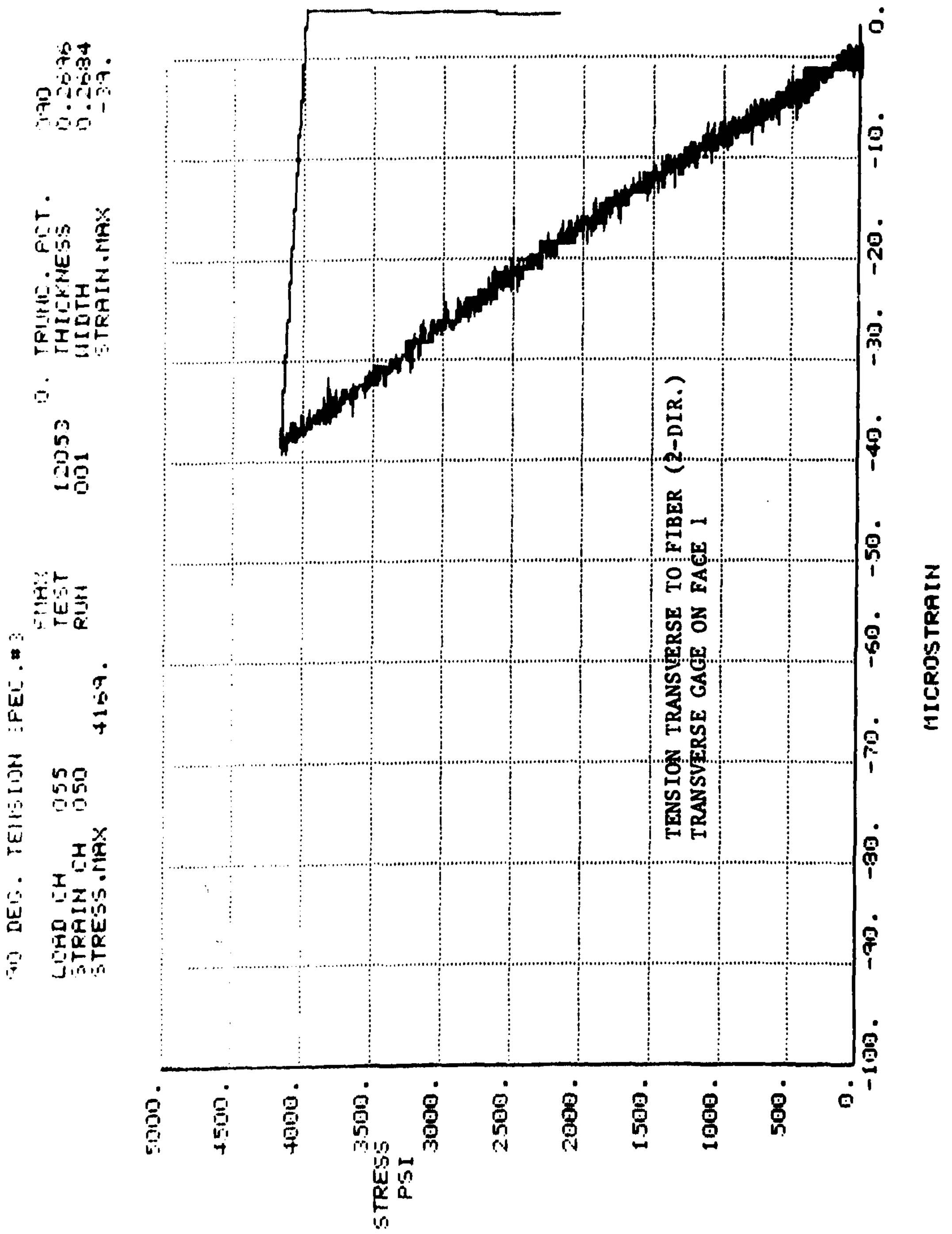
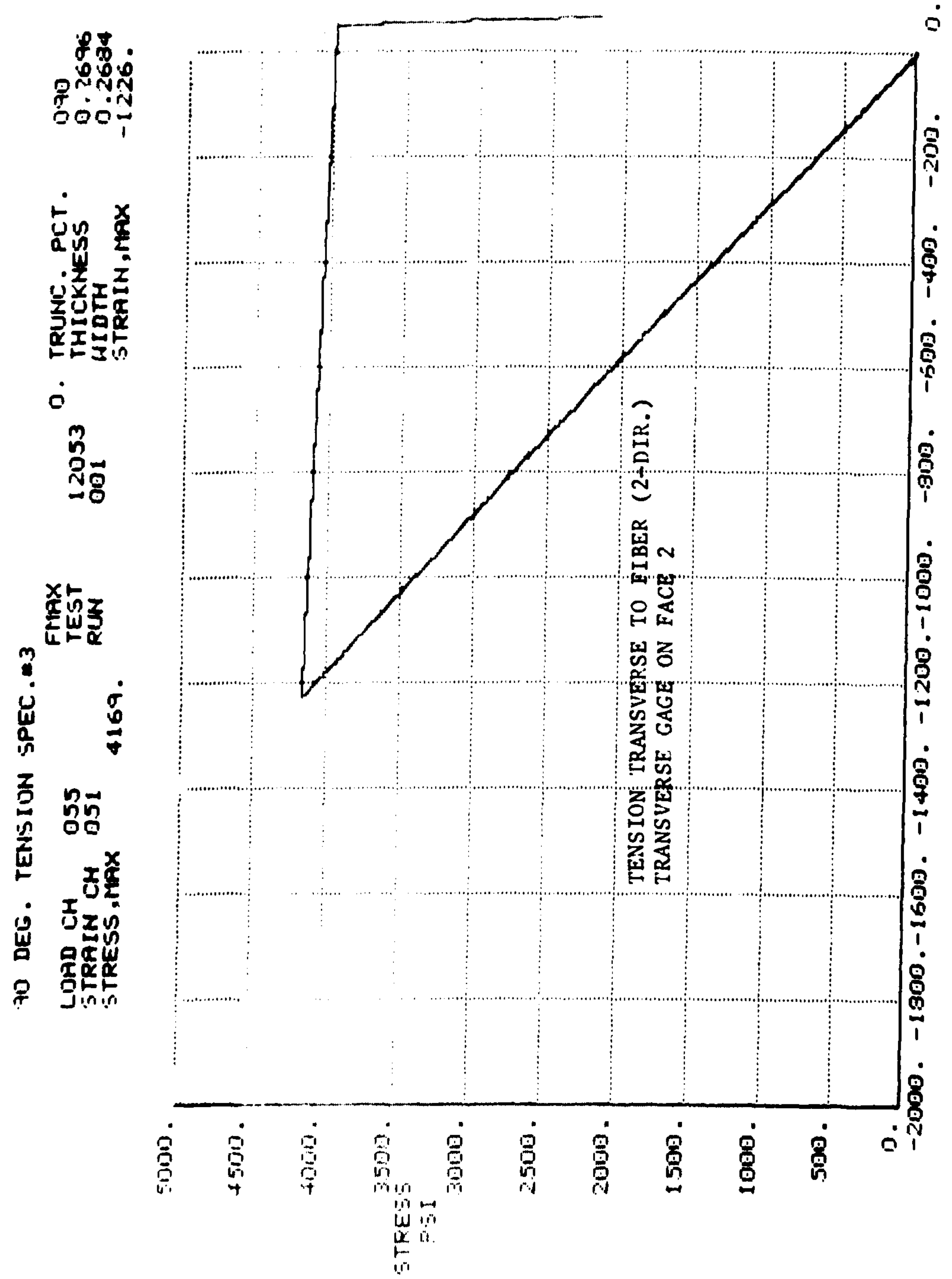
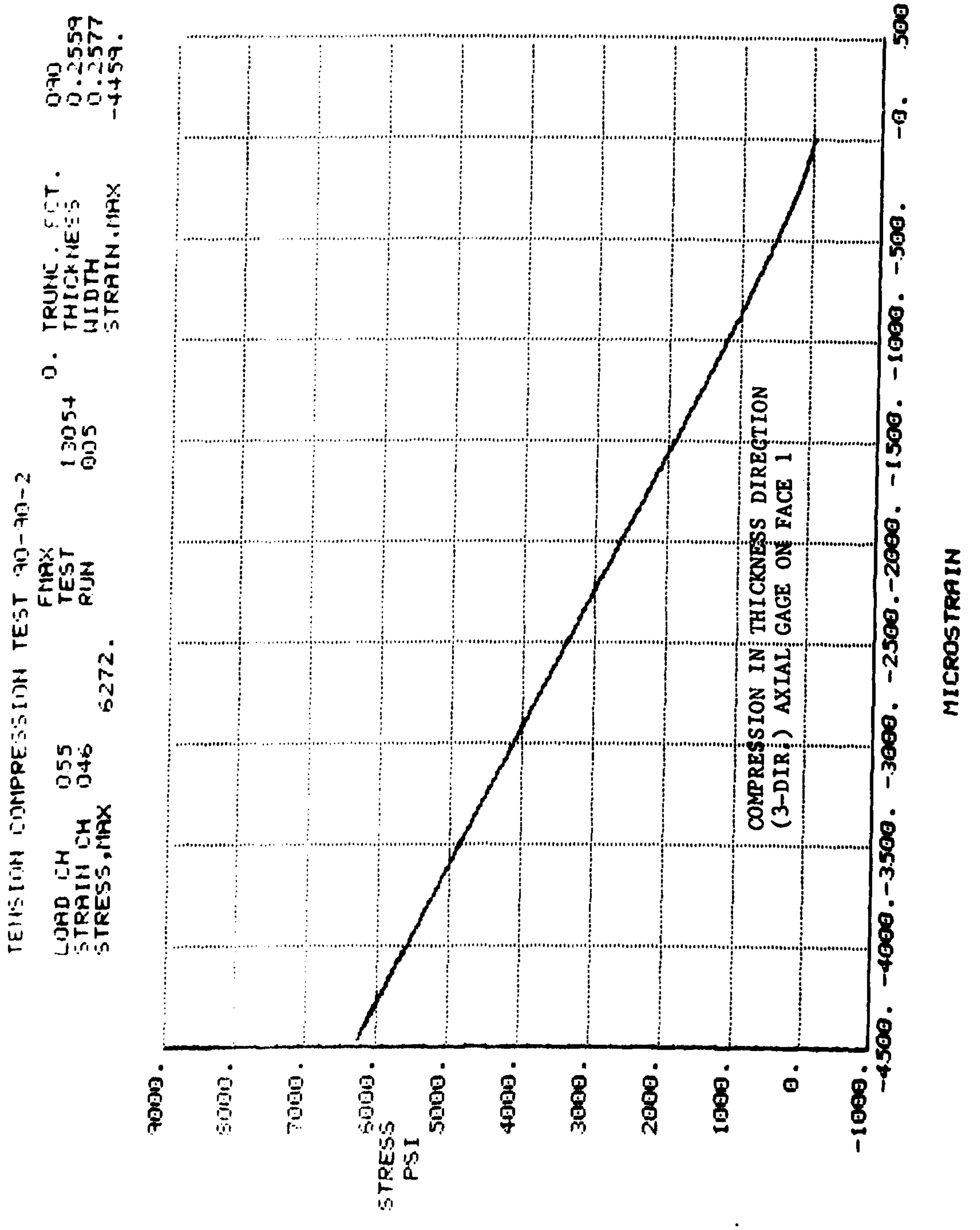
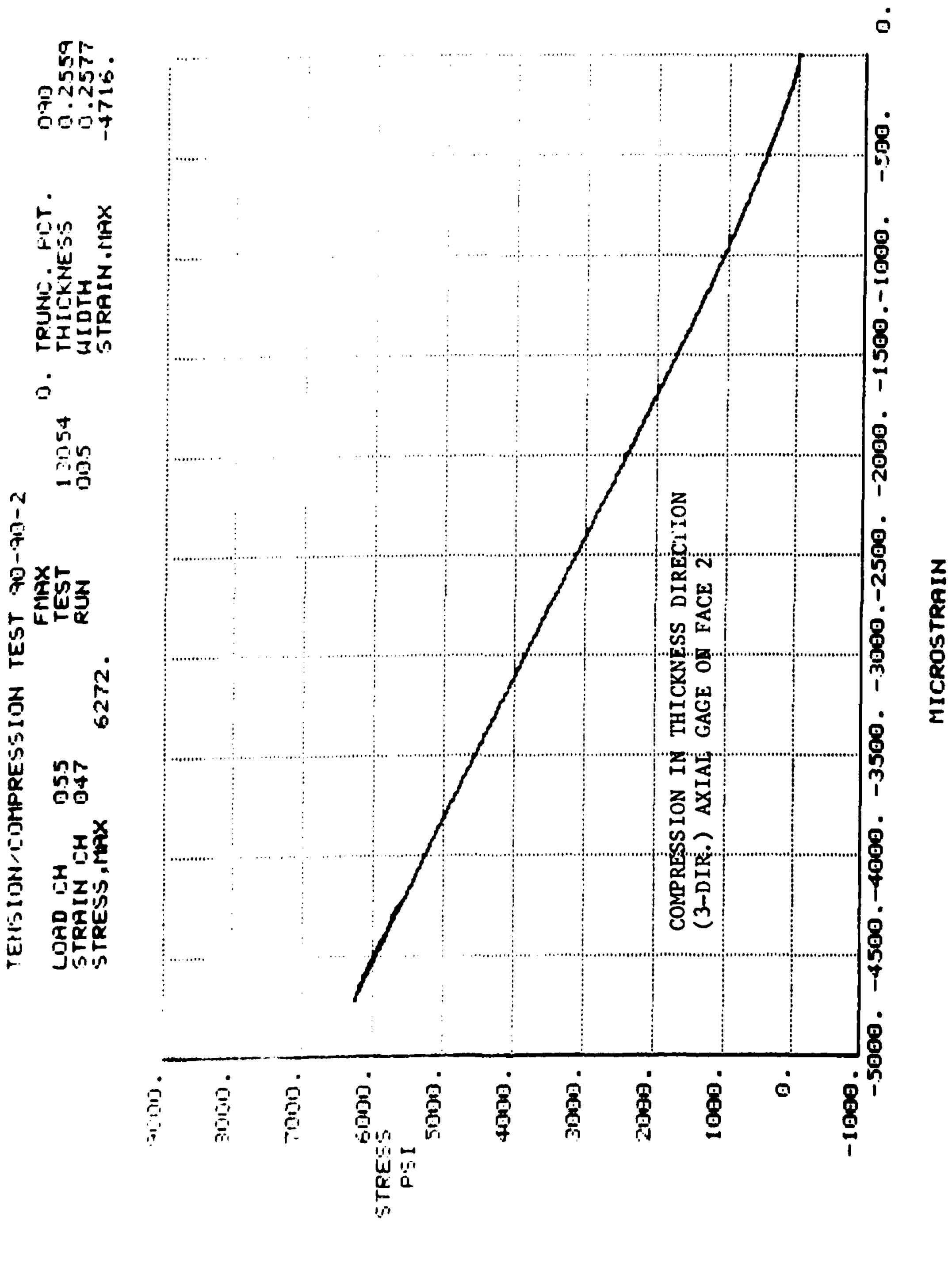
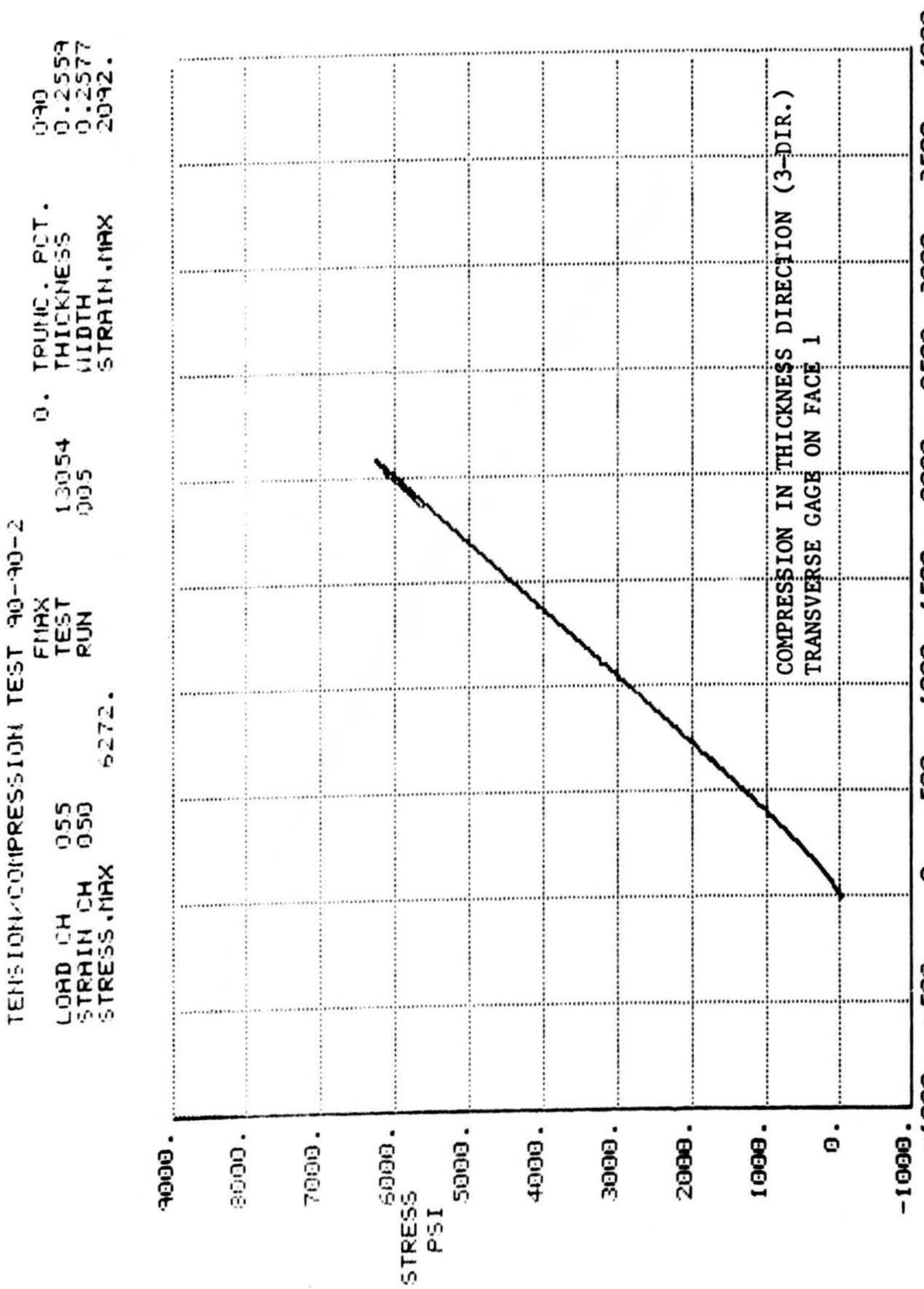


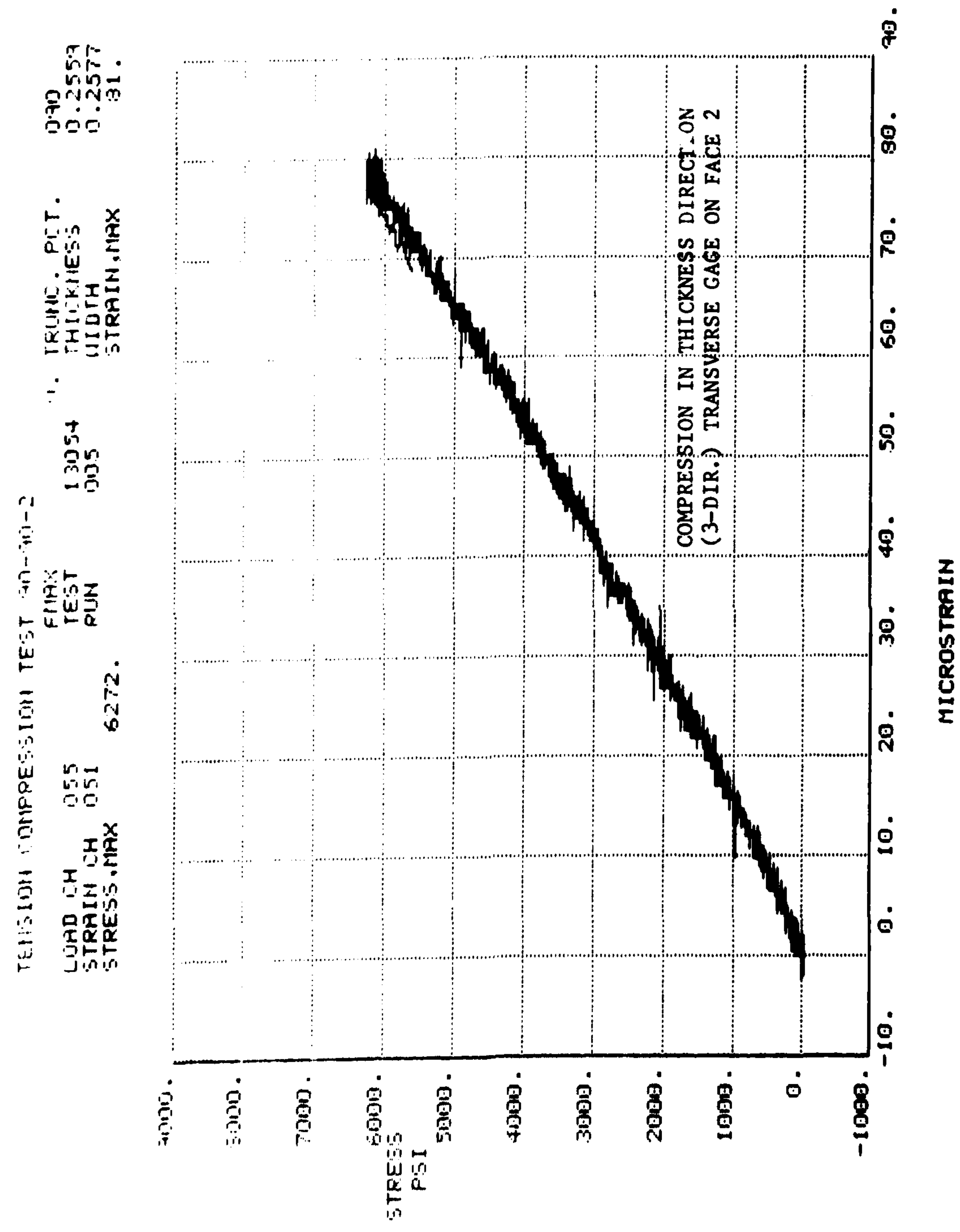
90 DEG. TENSION SPEC.#3
LOAD CH 055
STRAIN CH 050
STRESS.MAX 4169.
TEST 12053
RUN 001
TRUNC. PCT. 0.
THICKNESS
WIDTH
STRAIN.MAX
TENSION TRANSVERSE TO FIBER (2-DIR.)
TRANSVERSE GAGE ON FACE 1
STRESS PSI
MICROSTRAIN

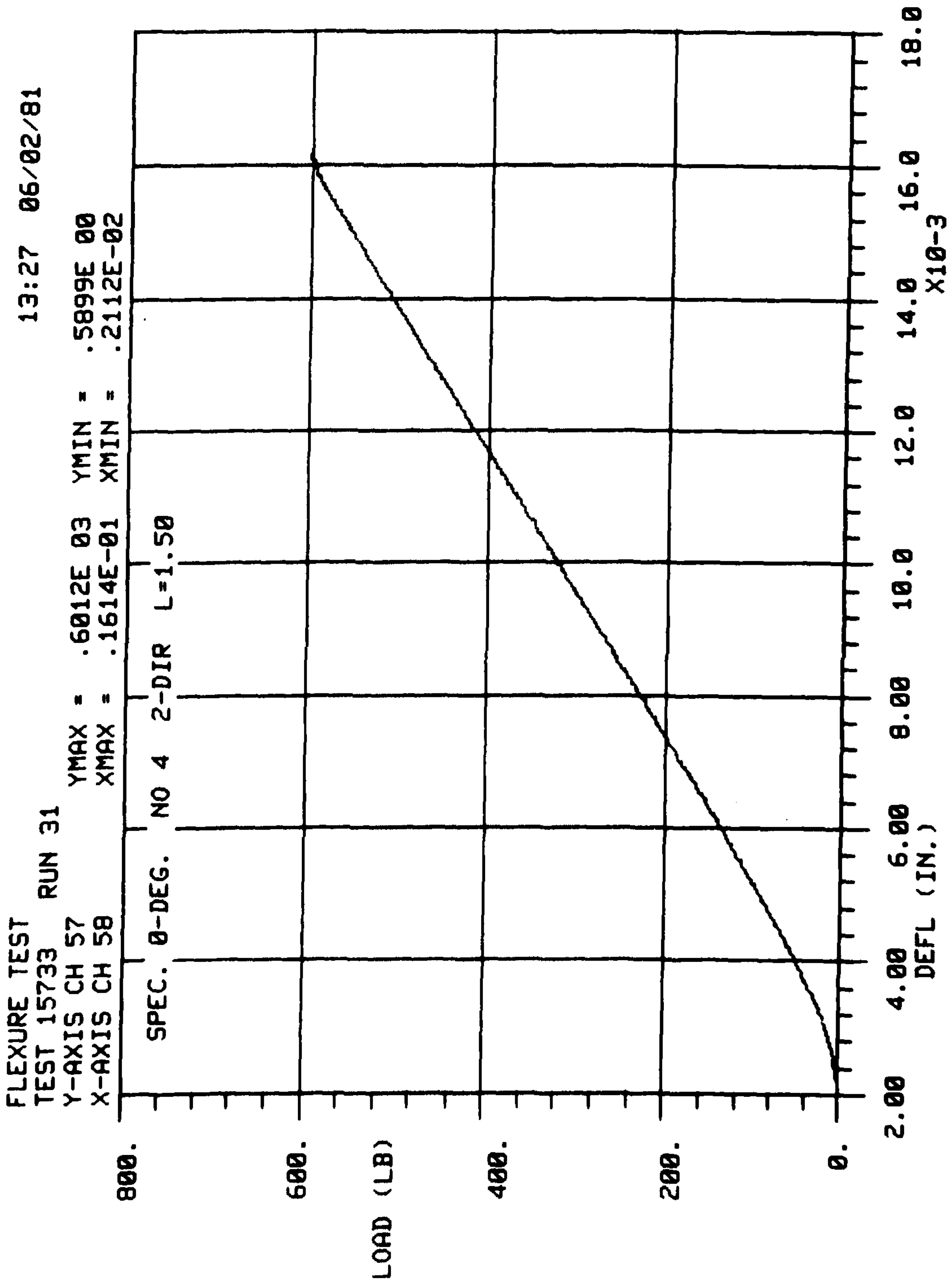

90 DEG. TENSION SPEC.#3
LOAD CH 055
STRAIN CH 051
STRESS,MAX 4169.
FMAX 12053
TEST 001
RUN
0. TRUNC. PCT. 090
THICKNESS 0.2696
WIDTH 0.2684
STRAIN,MAX -1226.
TENSION TRANSVERSE TO FIBER (2-DIR.)
TRANSVERSE GAGE ON FACE 2
STRESS PSI
5000.
4500.
4000.
3500.
3000.
2500.
2000.
1500.
1000.
500.
0.
-2000.
-1800.
-1600.
-1400.
-1200.
-1000.
-800.
-600.
-400.
-200.
0.
MICROSTRAIN


TENSION COMPRESSION TEST 90-90-2
FMAX 0.
TRUNC. FCT. 090
LOAD CH 055
TEST 13054
THICKNESS 0.2559
STRAIN CH 046
RUN 005
WIDTH 0.2577
STRESS,MAX 6272.
STRAIN,MAX -4459.
COMPRESSION IN THICKNESS DIRECTION
(3-DIR.) AXIAL GAGE ON FACE 1
STRESS
PSI
9000.
8000.
7000.
6000.
5000.
4000.
3000.
2000.
1000.
0.
-1000.
-4500.
-4000.
-3500.
-3000.
-2500.
-2000.
-1500.
-1000.
-500.
-0.
500.
MICROSTRAIN


TENSION/COMPRESSION TEST 90-90-2
LOAD CH 055
STRAIN CH 047
STRESS,MAX 6272.
FMAX 0.
TEST 13054
RUN 005
TRUNC. PCT. 090
THICKNESS 0.2559
WIDTH 0.2577
STRAIN,MAX -4716.
COMPRESSION IN THICKNESS DIRECTION
(3-DIR.) AXIAL GAGE ON FACE 2
STRESS
PSI
8000.
7000.
6000.
5000.
4000.
3000.
2000.
1000.
0.
-1000.
-5000.
-4500.
-4000.
-3500.
-3000.
-2500.
-2000.
-1500.
-1000.
-500.
0.
MICROSTRAIN


TENSION/COMPRESSION TEST 90-90-2
LOAD CH 055
STRAIN CH 050
STRESS.MAX 6272.
FMAX 13054
TEST 005
RUN
0. TRUNC. PCT. 090
THICKNESS 0.2559
WIDTH 0.2577
STRAIN.MAX 2092.
COMPRESSION IN THICKNESS DIRECTION (3-DIR.)
TRANSVERSE GAGE ON FACE 1
STRESS PSI
9000. 8000. 7000. 6000. 5000. 4000. 3000. 2000. 1000. 0. -1000.
MICROSTRAIN
-1000. -500. 0. 500. 1000. 1500. 2000. 2500. 3000. 3500. 4000.


TENSION COMPRESSION TEST
LOAD CH 055
STRAIN CH 051
STRESS,MAX 6272.
FMAX 13054
TEST 005
RUN
TRUNC. PCT. 090
THICKNESS 0.2553
WIDTH 0.2577
STRAIN,MAX 81.
COMPRESSION IN THICKNESS DIRECT.ON
(3-DIR.) TRANSVERSE GAGE ON FACE 2
STRESS
PSI
-1000.
0.
1000.
2000.
3000.
4000.
5000.
6000.
7000.
-10.
0.
10.
20.
30.
40.
50.
60.
70.
80.
MICROSTRAIN



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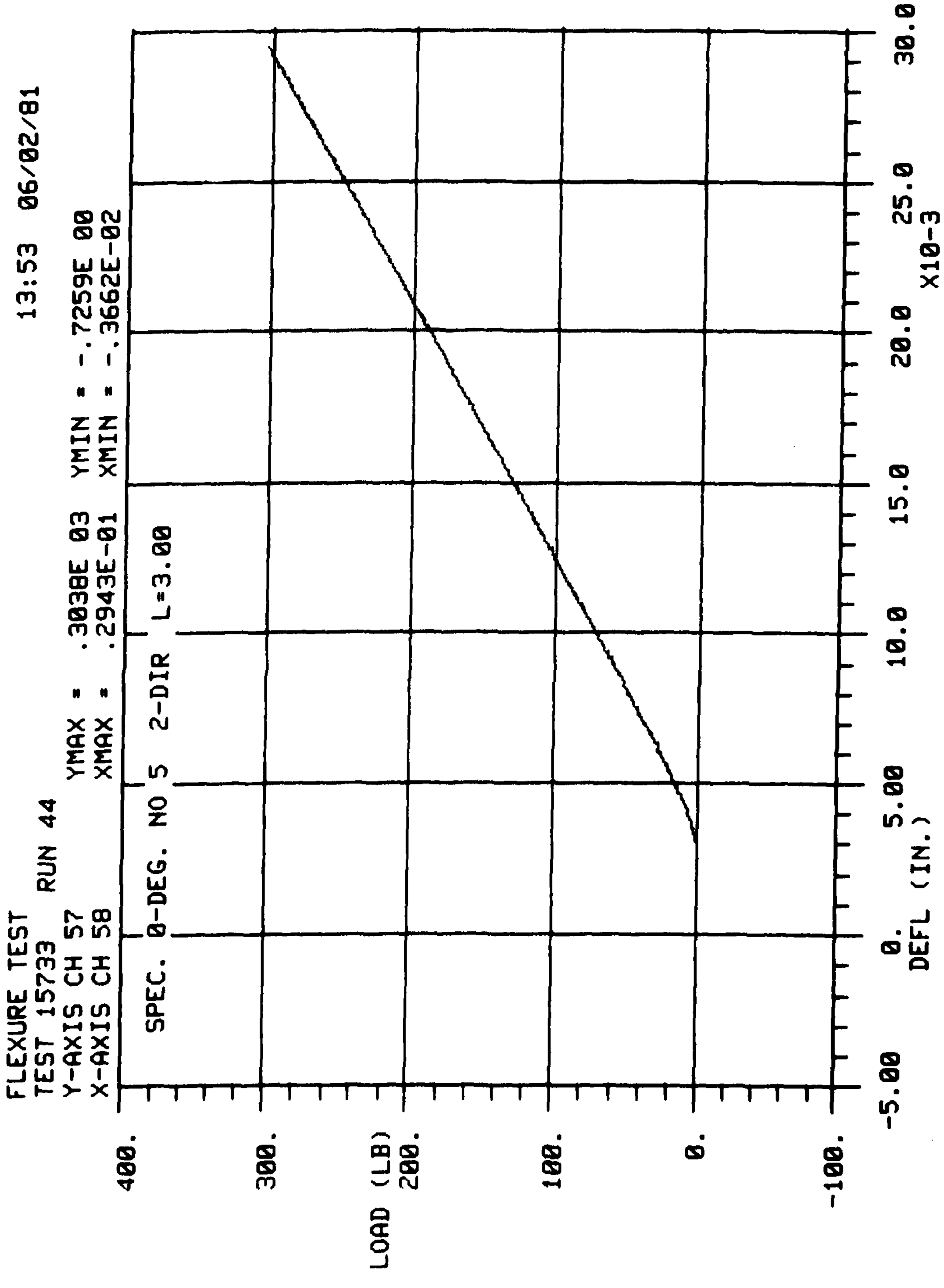

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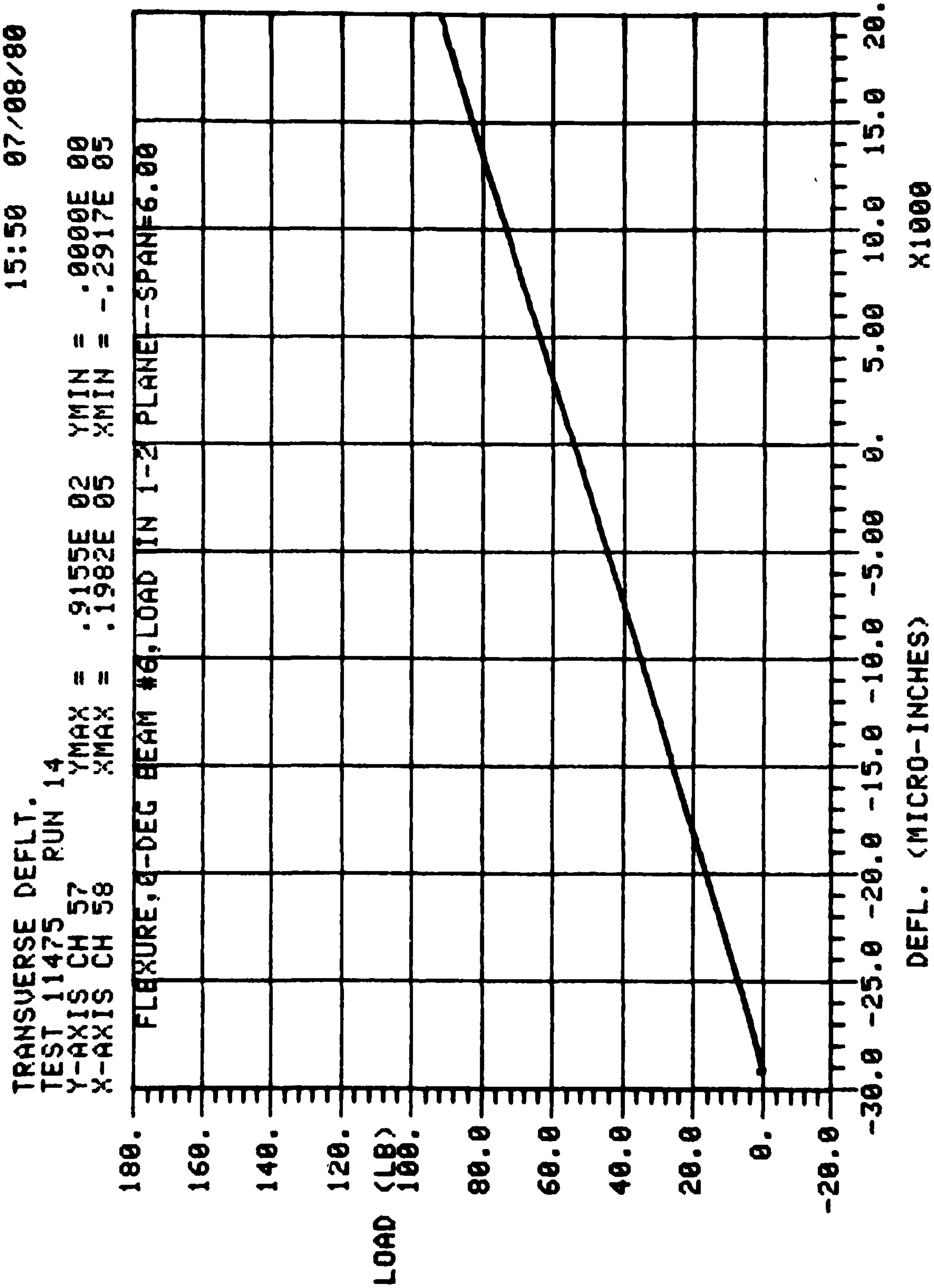
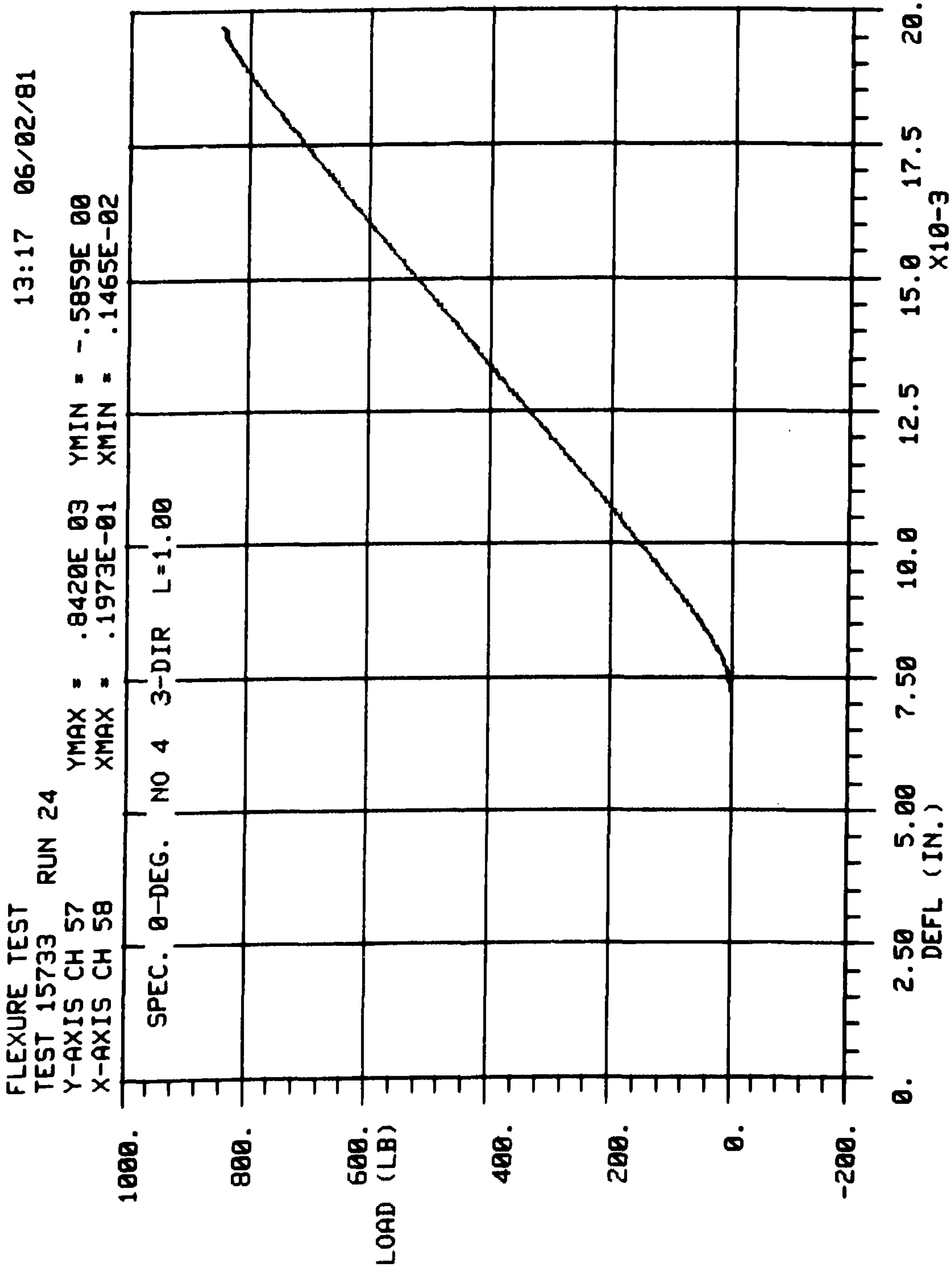

TRANSVERSE DEFLT.
TEST 11475 RUN 14
Y-AXIS CH 57 YMAX = .9155E 02 YMIN = .0000E 00
X-AXIS CH 58 XMAX = .1982E 05 XMIN = -.2917E 05
15:50 07/08/80
FLEXURE,0-DEG BEAM #6,LOAD IN 1-2 PLANE--SPAN=6.00
180. 160. 140. 120. 100. 80.0 60.0 40.0 20.0 0. -20.0
LOAD (LB)
-30.0 -25.0 -20.0 -15.0 -10.0 -5.00 0. 5.00 10.0 15.0 20.0
DEFL. (MICRO-INCHES) X1000



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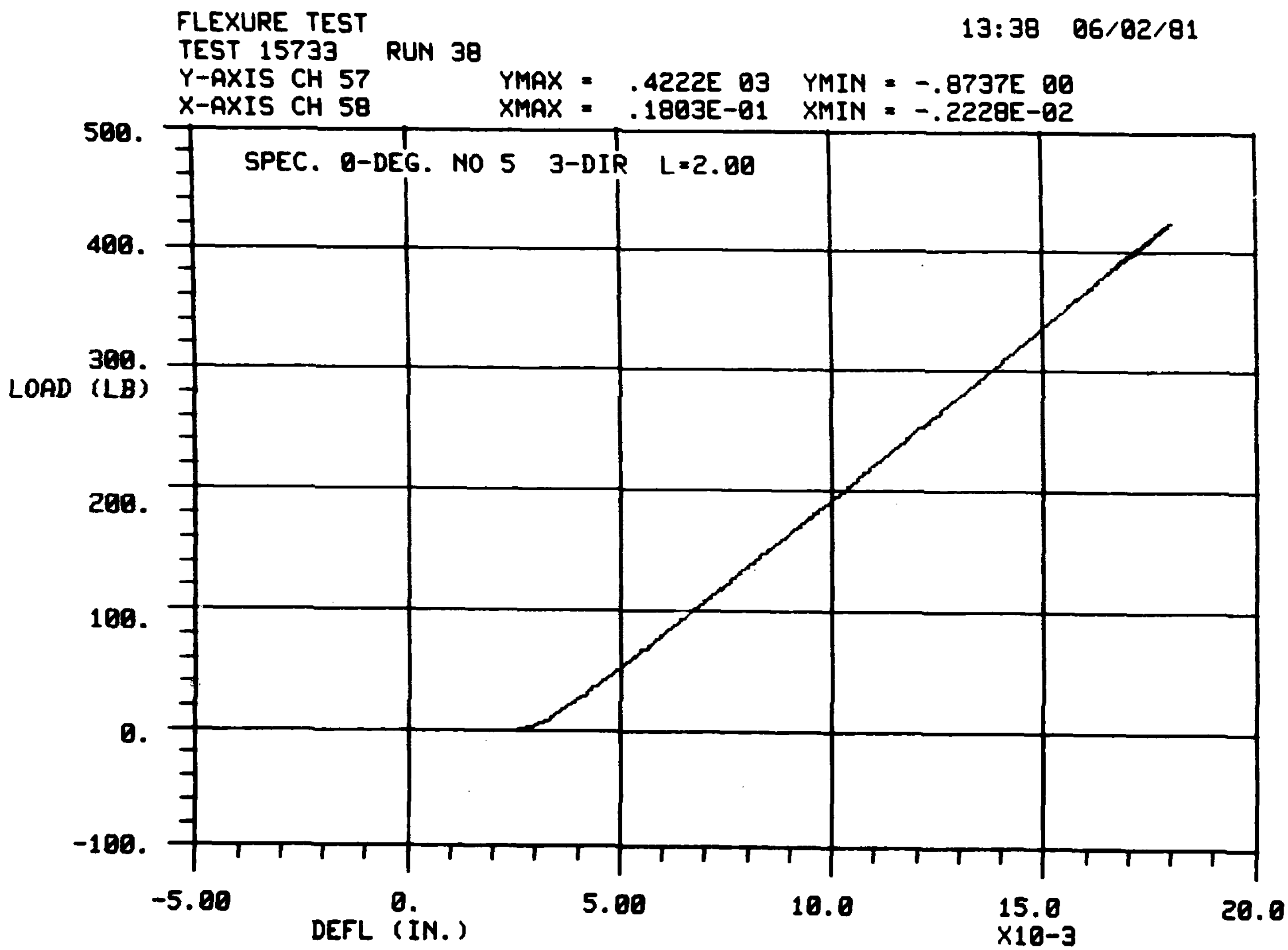
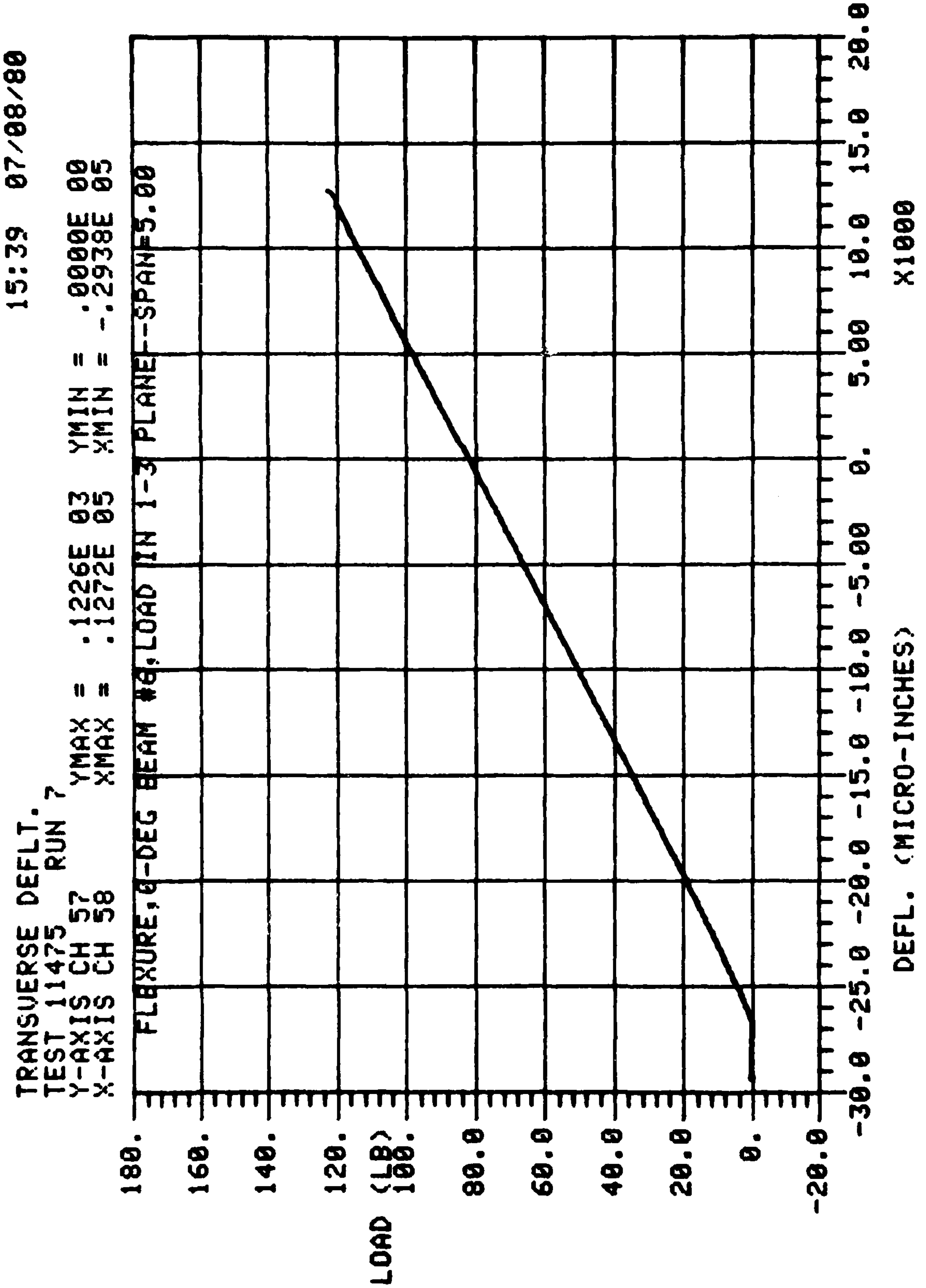
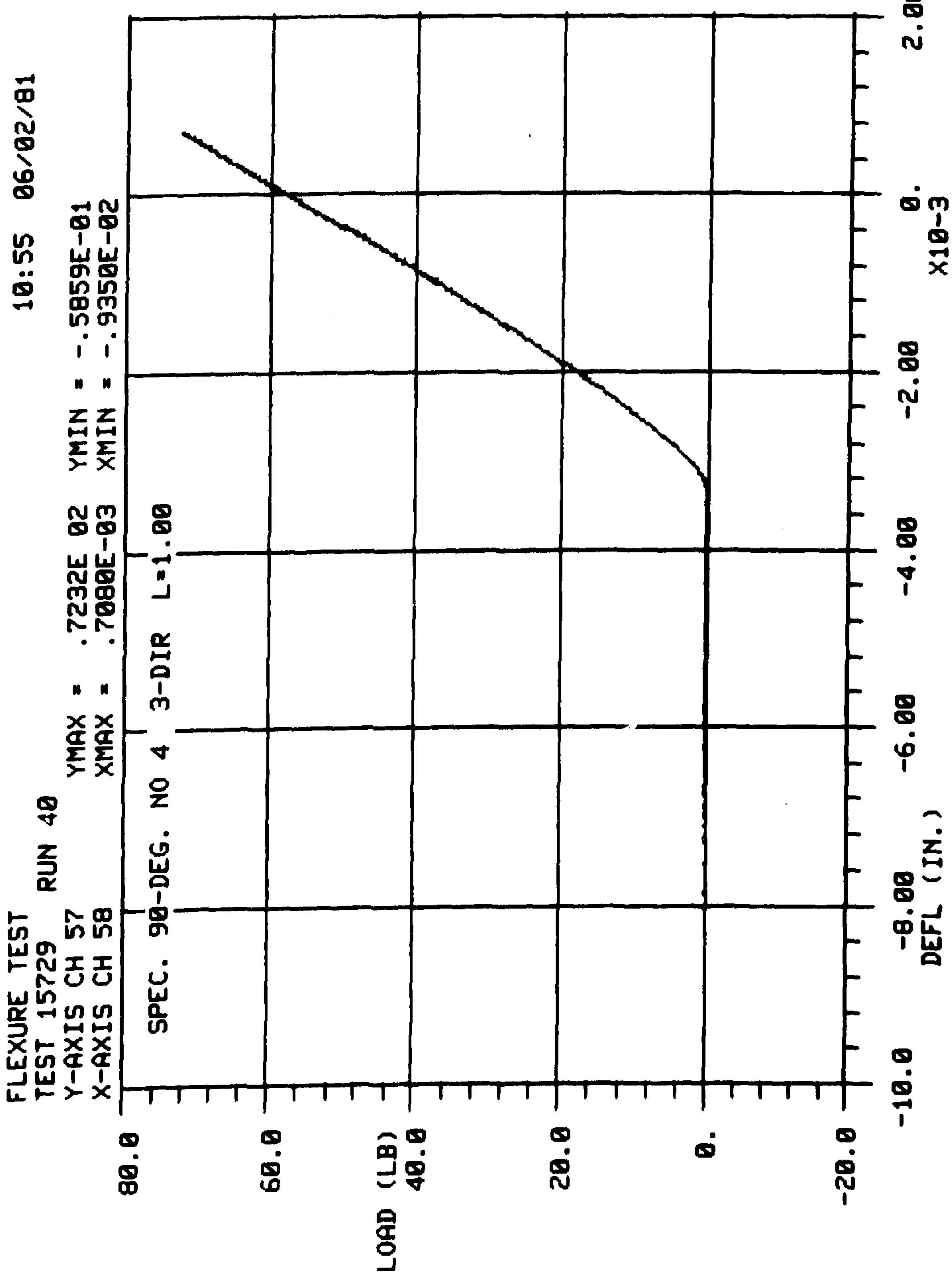
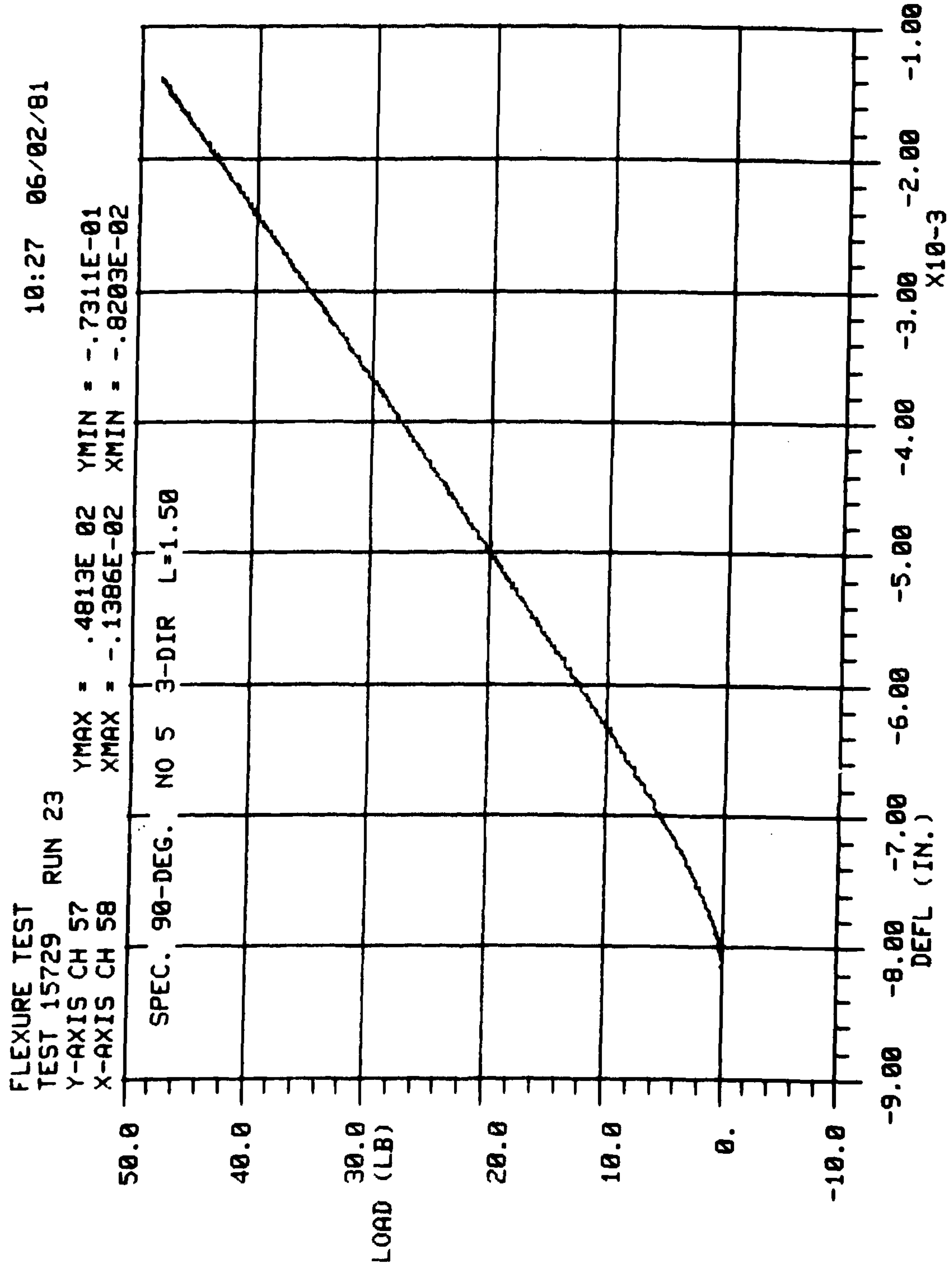


FLEXURE TEST
TEST 15733 RUN 38
Y-AXIS CH 57
X-AXIS CH 58
13:38 06/02/81
YMAX = .4222E 03 YMIN = -.8737E 00
XMAX = .1803E-01 XMIN = -.2228E-02
SPEC. 0-DEG. NO 5 3-DIR L=2.00
LOAD (LB)
500.
400.
300.
200.
100.
0.
-100.
DEFL (IN.)
-5.00
0.
5.00
10.0
15.0
20.0
X10-3


TRANSVERSE DEFLT.
TEST 11475 RUN 7
Y-AXIS CH 57 YMAX = .1226E 03 YMIN = .0000E 00
X-AXIS CH 58 XMAX = .1272E 05 XMIN = -.2938E 05
15:39 07/08/80
FLEXURE,0-DEG BEAM #6,LOAD IN 1-3 PLANE--SPAN=5.00
LOAD (LB)
180. 160. 140. 120. 100. 80.0 60.0 40.0 20.0 0. -20.0
DEFL. (MICRO-INCHES)
X1000
-30.0 -25.0 -20.0 -15.0 -10.0 -5.00 0. 5.00 10.0 15.0 20.0


FLEXURE TEST
TEST 15729 RUN 40
10:55 06/02/81
Y-AXIS CH 57 YMAX = .7232E 02 YMIN = -.5859E-01
X-AXIS CH 58 XMAX = .7080E-03 XMIN = -.9350E-02
SPEC. 90-DEG. NO 4 3-DIR L=1.00
80.0
60.0
40.0
20.0
0.
-20.0
LOAD (LB)
-10.0
-8.00
-6.00
-4.00
-2.00
0.
2.00
X10-3
DEFL (IN.)



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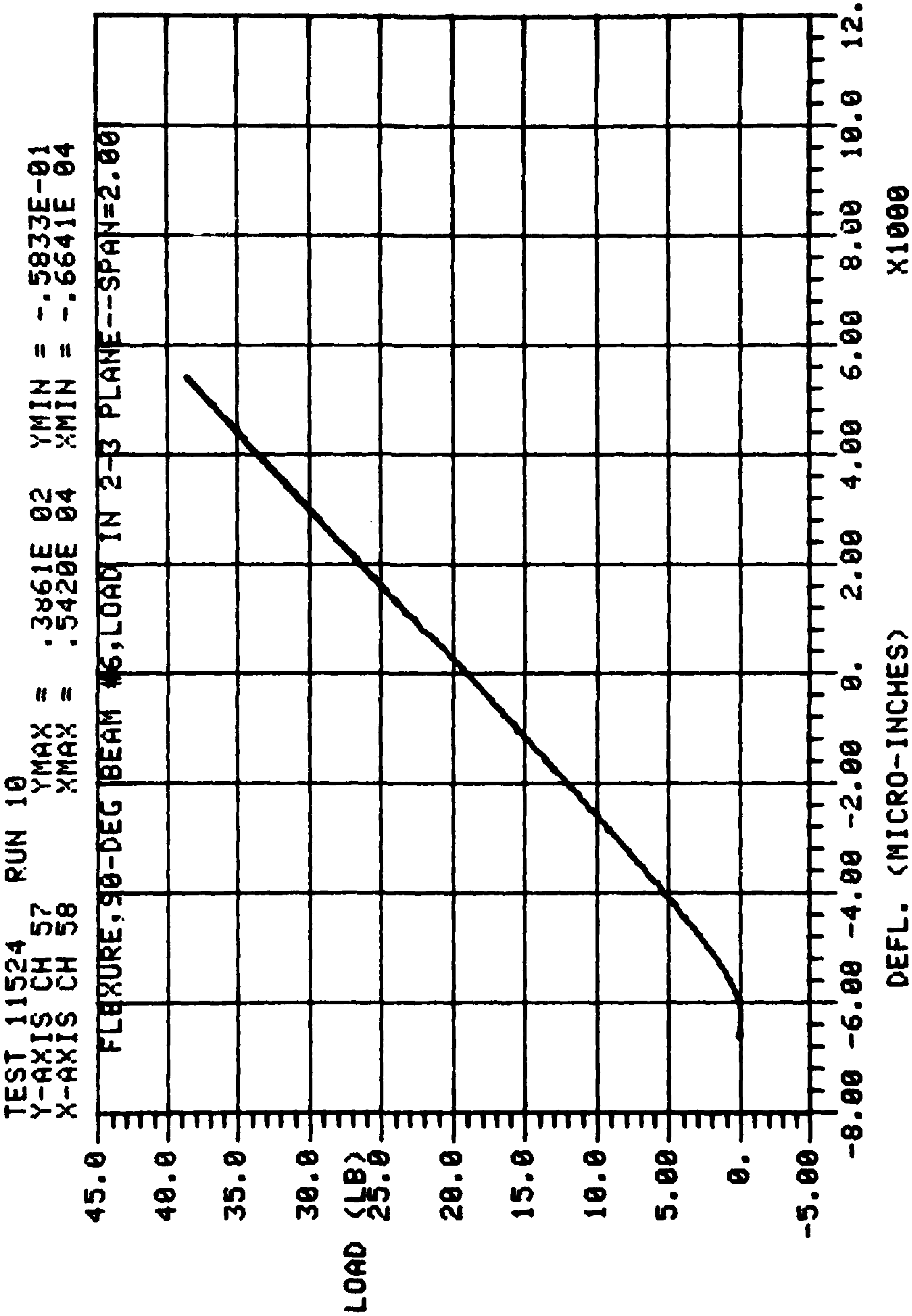
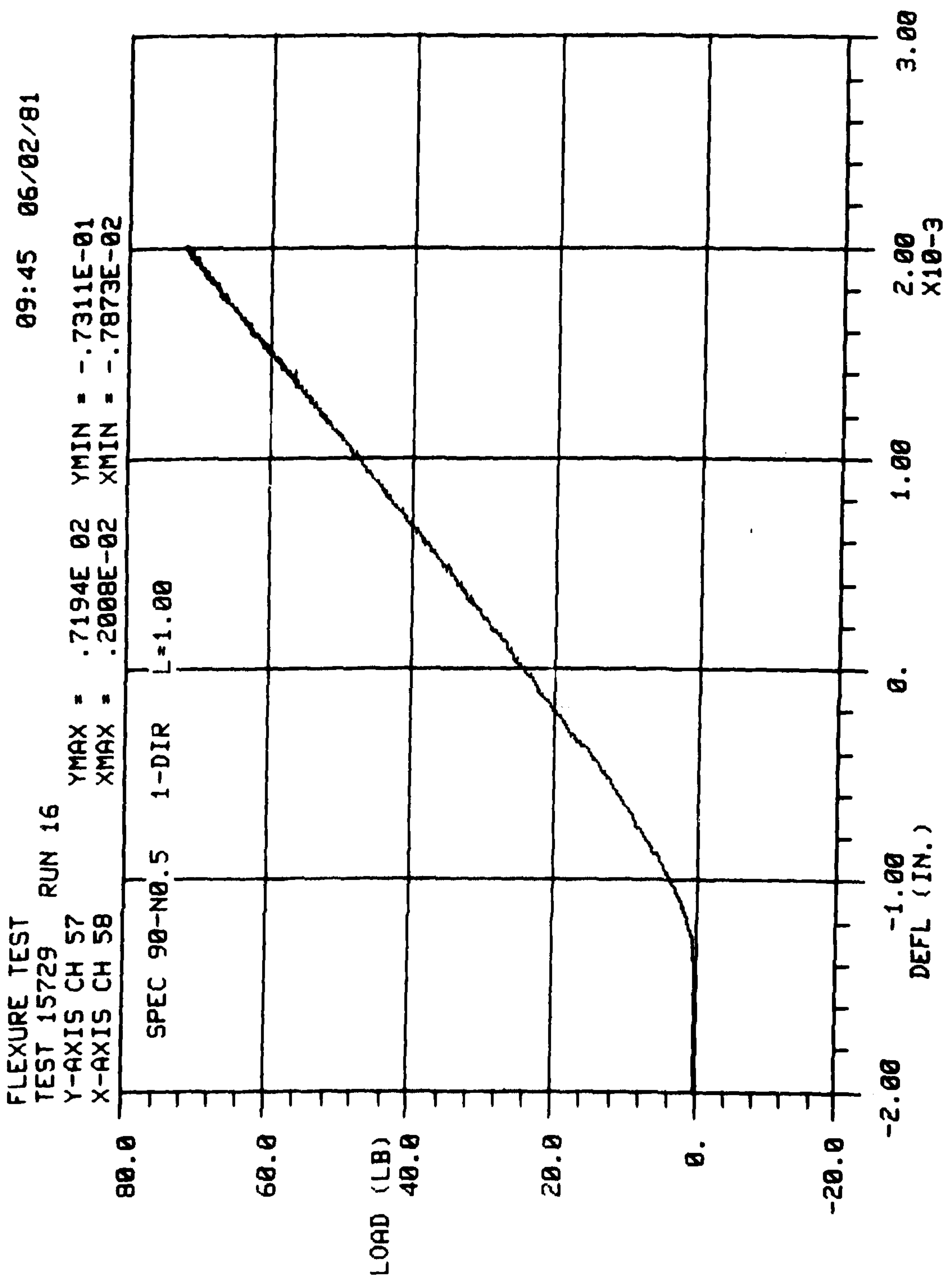

TEST 11524 RUN 10 10:48 07/11/80
Y-AXIS CH 57 YMAX = .3861E 02 YMIN = -.5833E-01
X-AXIS CH 58 XMAX = .5420E 04 XMIN = -.6641E 04
FLEXURE,90-DEG BEAM #6,LOAD IN 2-3 PLANE--SPAN=2.00
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.00
0.
-5.00
LOAD (LB)
-8.00 -6.00 -4.00 -2.00 0. 2.00 4.00 6.00 8.00 10.0 12.0
X1000
DEFL. (MICRO-INCHES)



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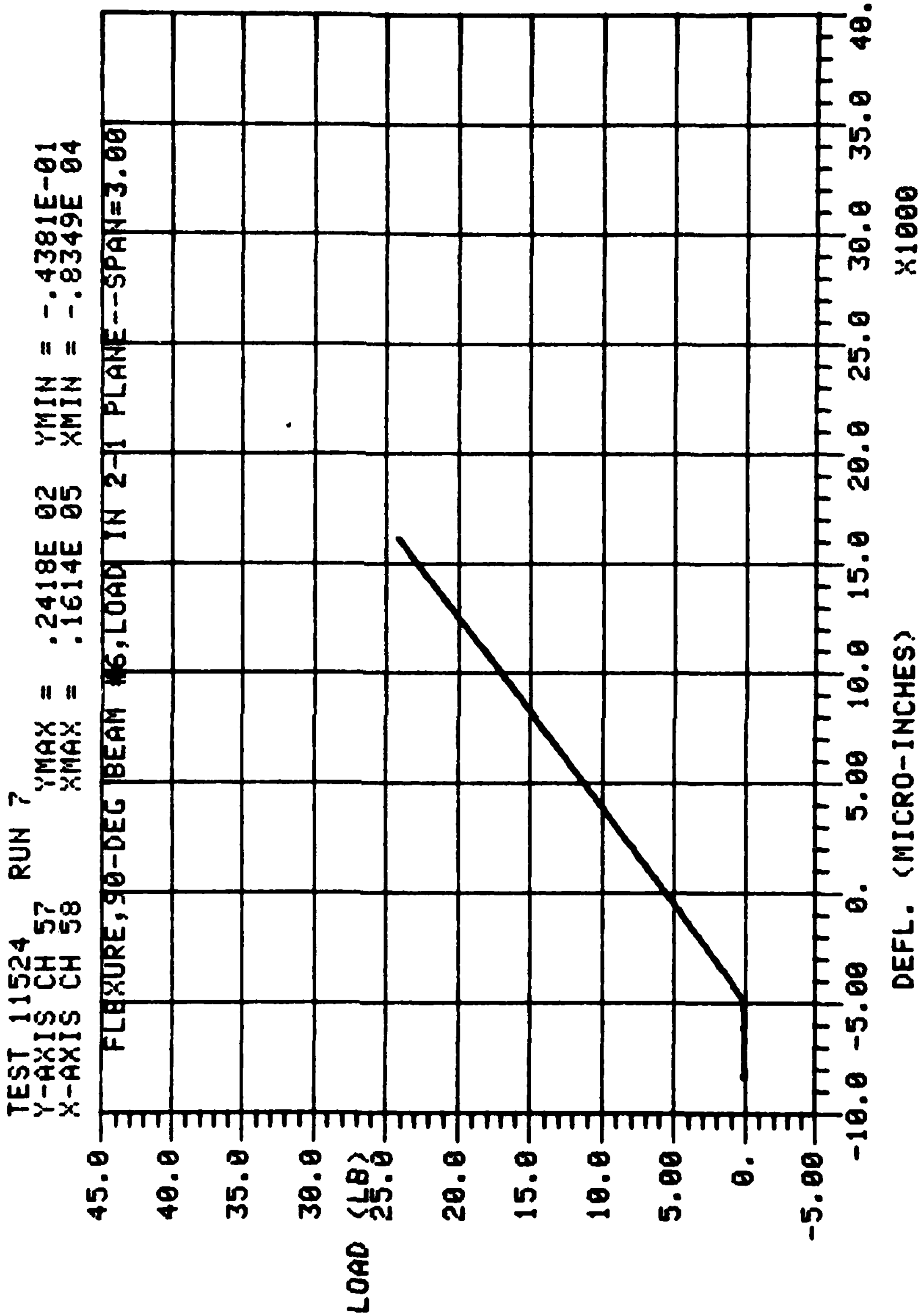

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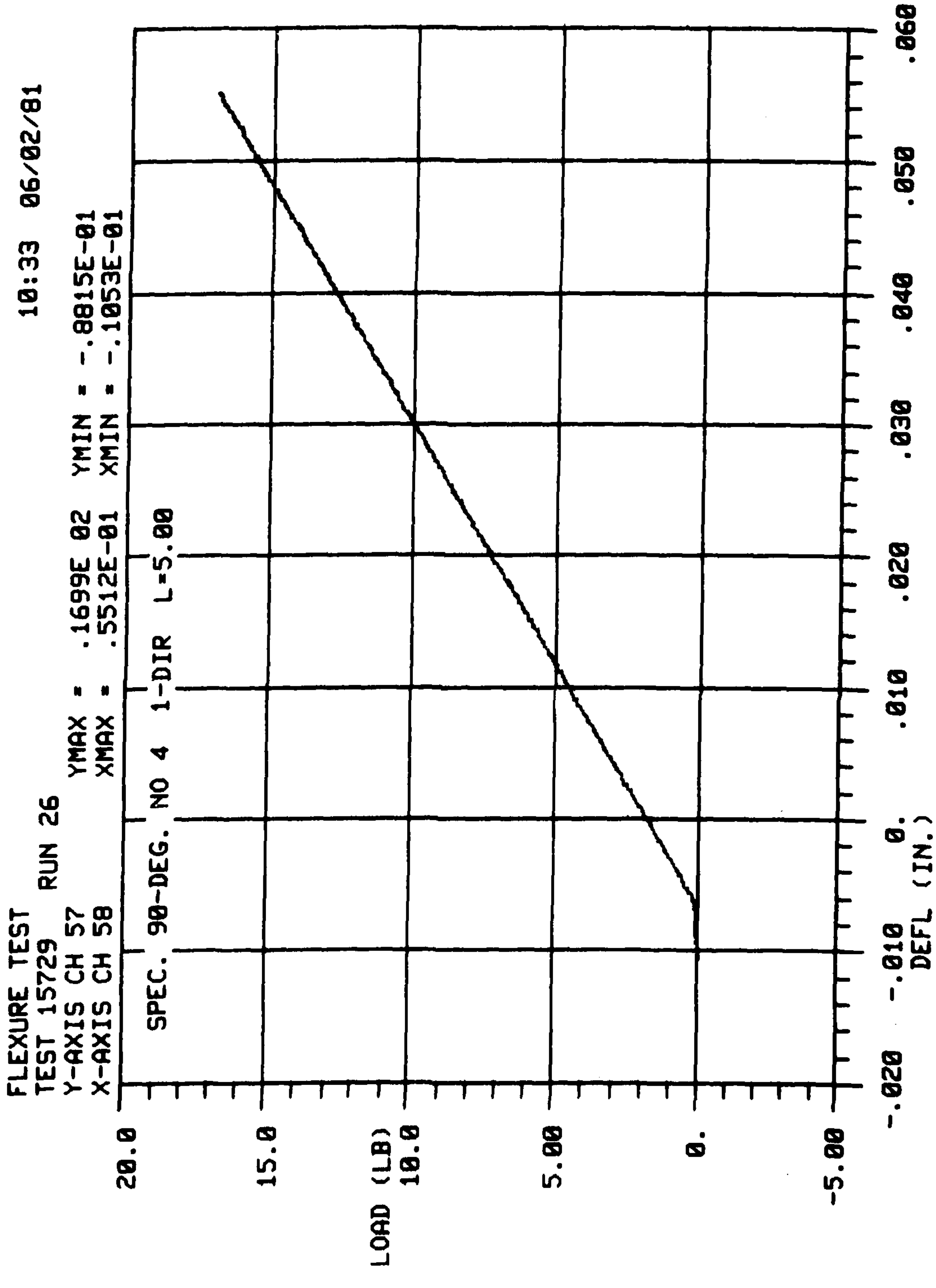

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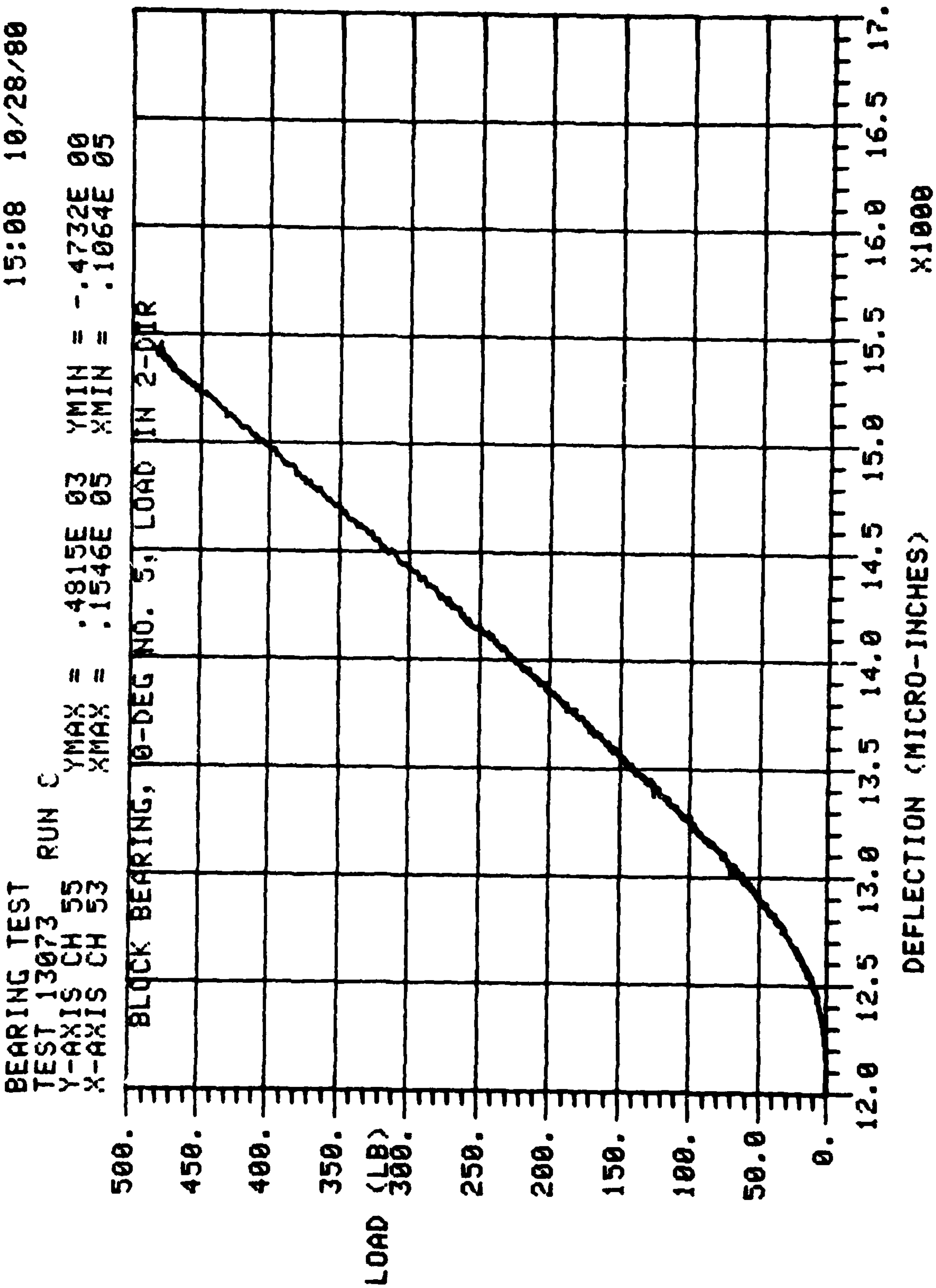
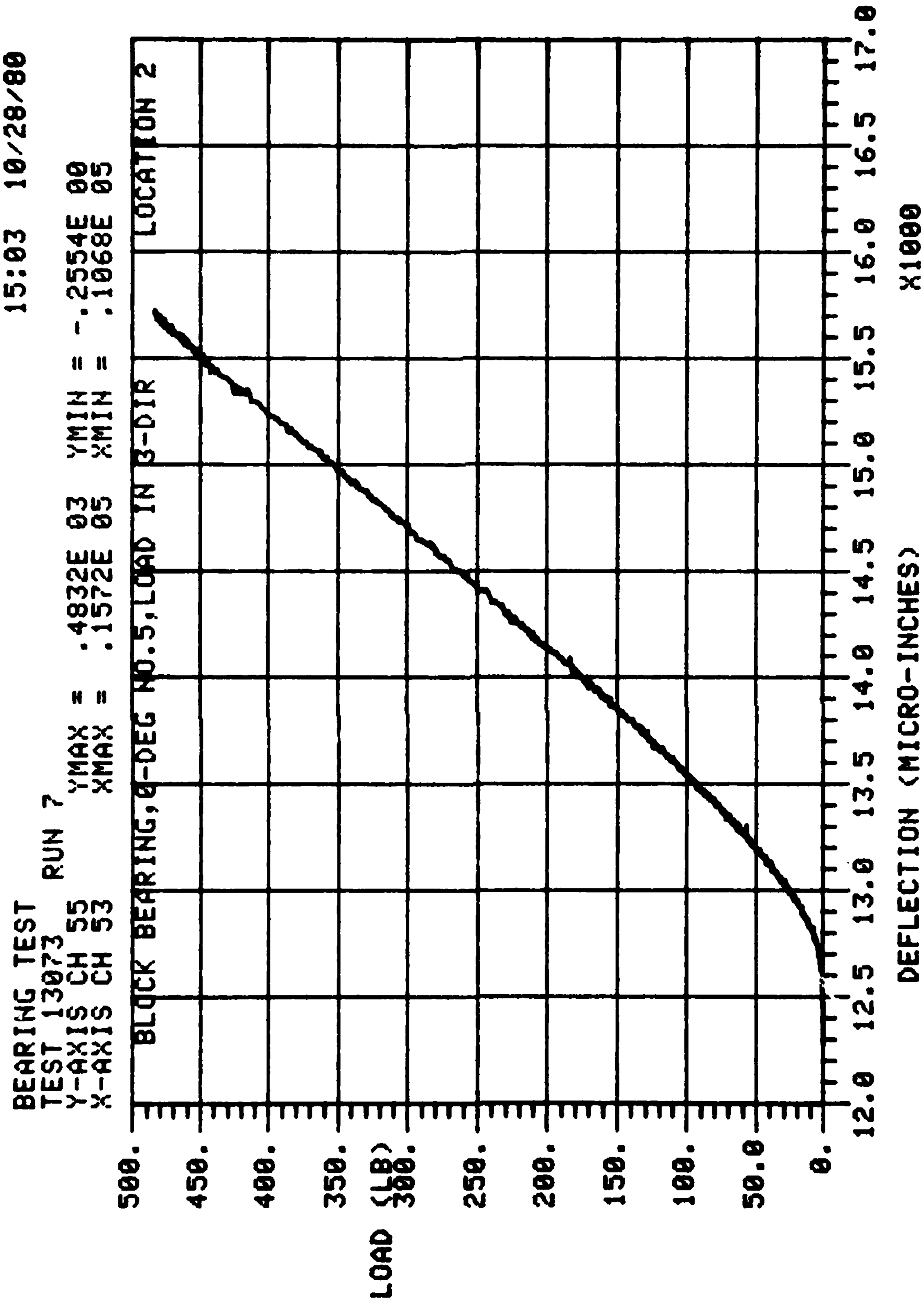
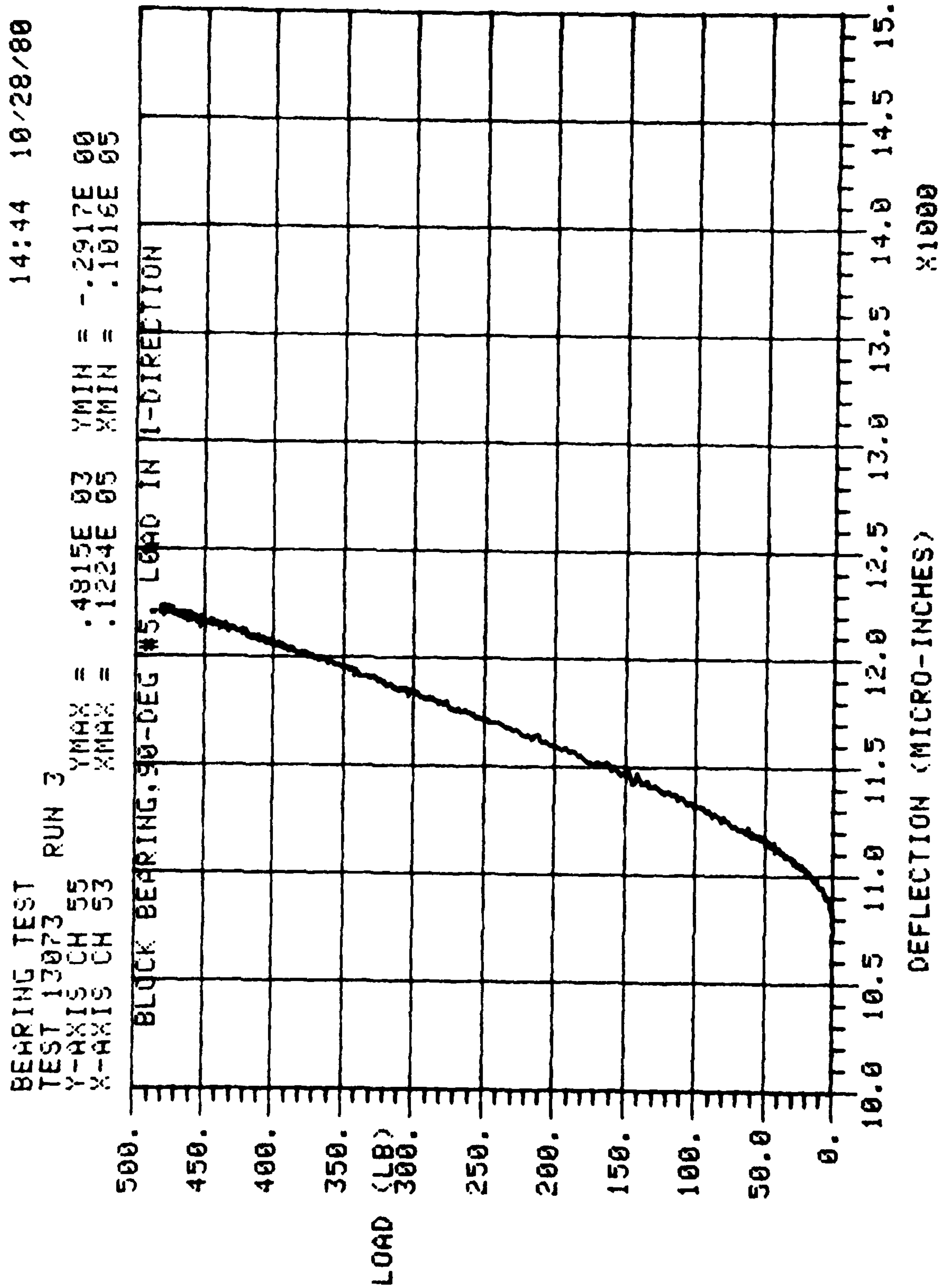
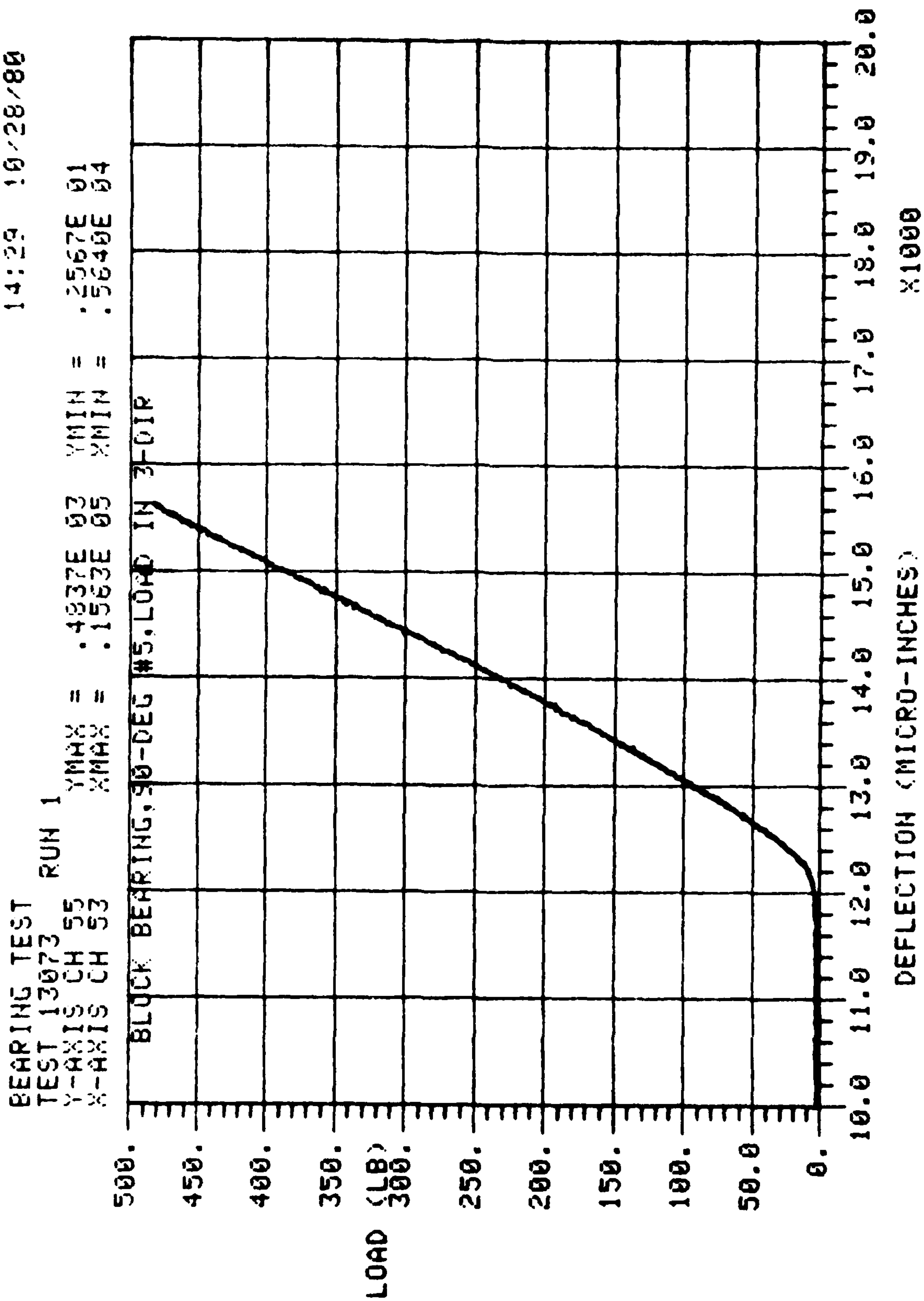
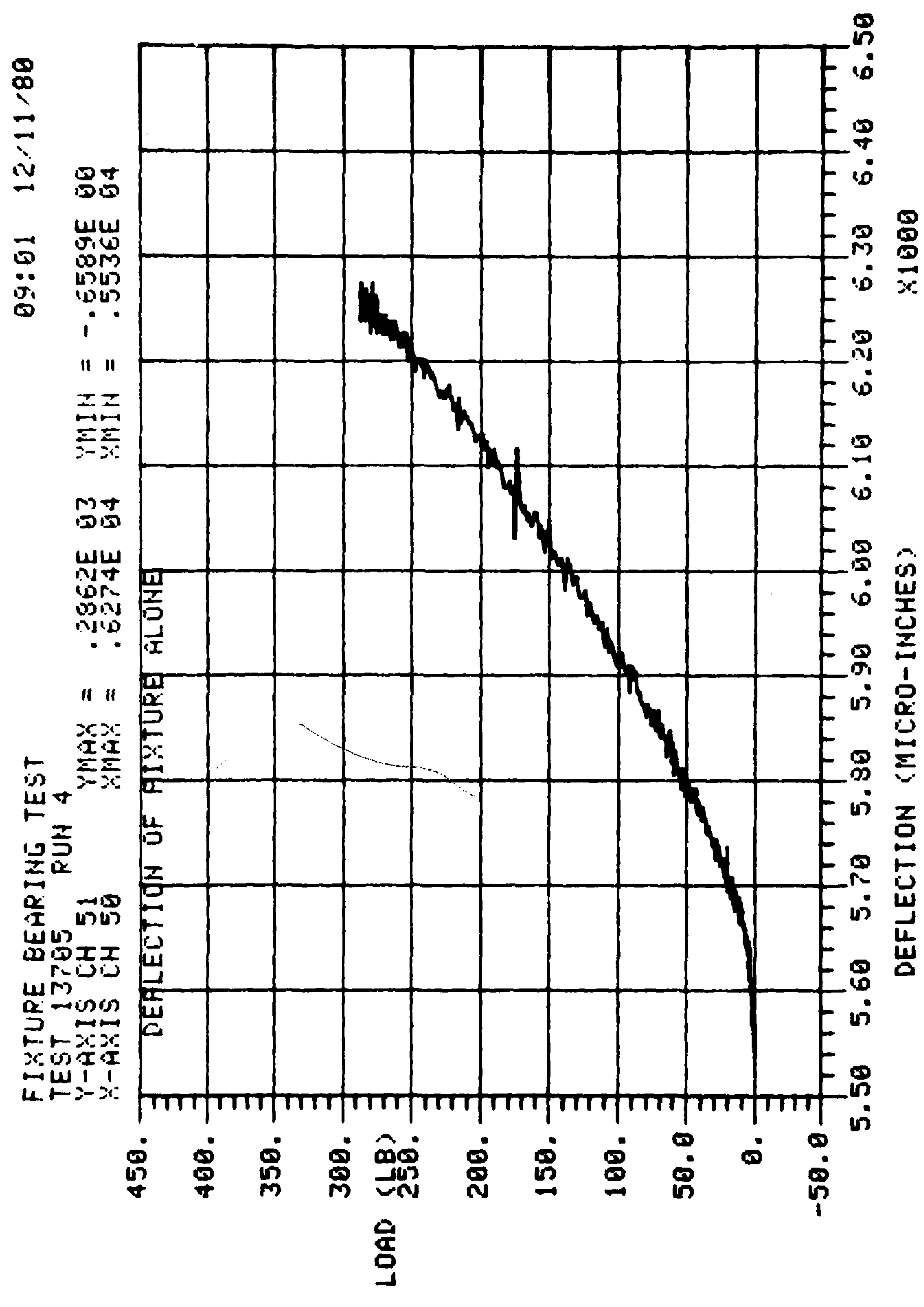
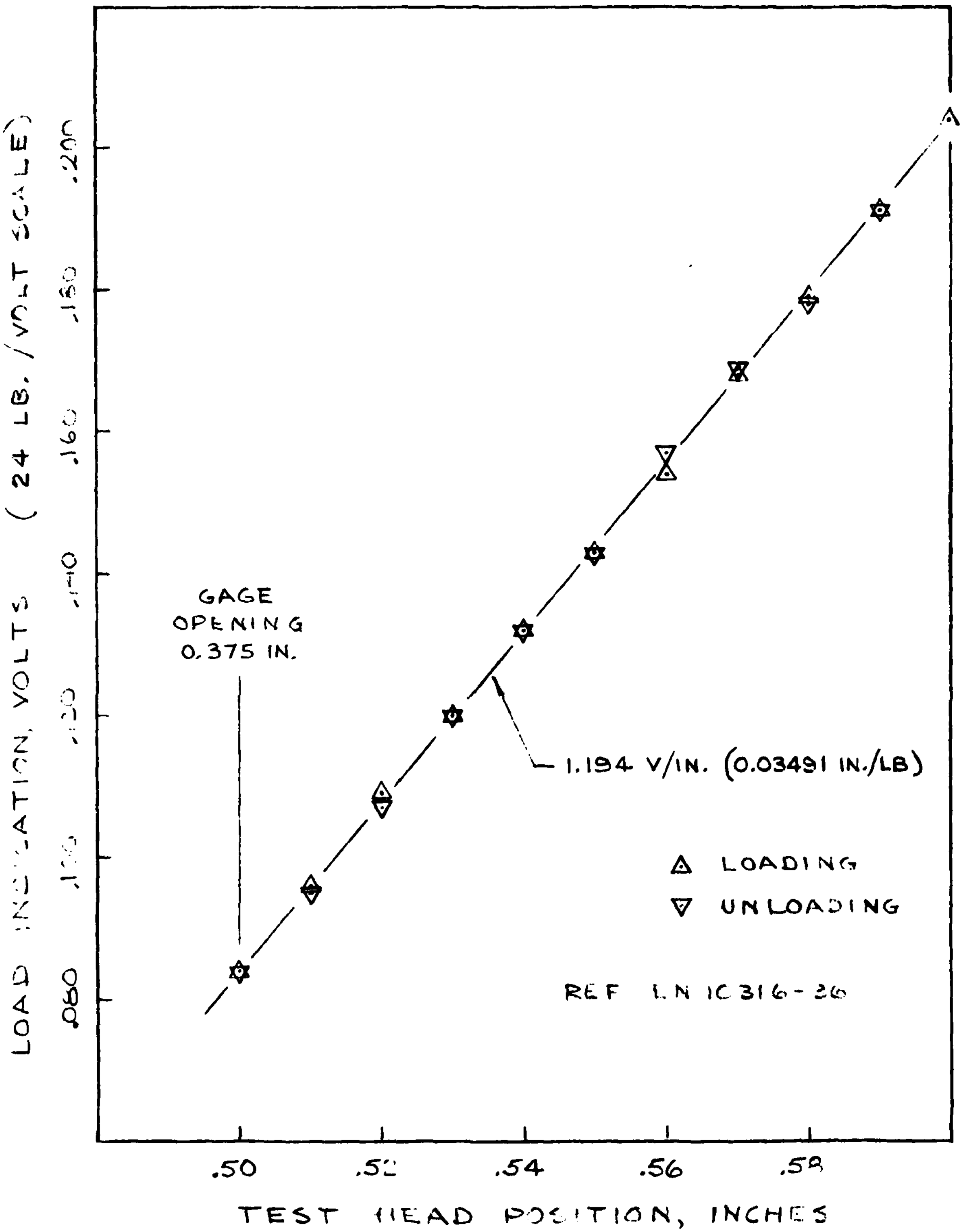

BEARING TEST
TEST 13073 RUN C
Y-AXIS CH 55
X-AXIS CH 53
15:08 10/28/80
YMAX = .4815E 03 YMIN = -.4732E 00
XMAX = .1546E 05 XMIN = .1064E 05
BLOCK BEARING, 0-DEG NO. 5, LOAD IN 2-DIR
LOAD (LB)
500.
450.
400.
350.
300.
250.
200.
150.
100.
50.0
0.
DEFLECTION (MICRO-INCHES)
X1000
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
17.0


BEARING TEST
TEST 13073 RUN 7
Y-AXIS CH 55 YMAX = .4832E 03 YMIN = -.2554E 00
X-AXIS CH 53 XMAX = .1572E 05 XMIN = .1068E 05
15:03 10/28/80
BLOCK BEARING,0-DEG NO.5,LOAD IN 3-DIR LOCATION 2
LOAD (LB)
500.
450.
400.
350.
300.
250.
200.
150.
100.
50.0
0.
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
17.0
DEFLECTION (MICRO-INCHES)
X1000


BEARING TEST
TEST 13073 RUN 3
Y-AXIS CH 55
X-AXIS CH 53
YMAX = .4815E 03
XMAX = .1224E 05
YMIN = -.2917E 00
XMIN = .1016E 05
14:44 10/28/80
BLOCK BEARING,90-DEG #5, LOAD IN 1-DIRECTION
500.
450.
400.
350.
300.
250.
200.
150.
100.
50.0
0.
LOAD (LB)
10.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
X1000
DEFLECTION (MICRO-INCHES)


BEARING TEST
TEST 13073 RUN 1
Y-AXIS CH 55
X-AXIS CH 53
YMAX = .4837E 03
XMAX = .1563E 05
YMIN = .2567E 01
XMIN = .5640E 04
14:29 10/28/80
BLOCK BEARING,90-DEG #5,LOAD IN 3-DIR
500.
450.
400.
350.
300.
250.
200.
150.
100.
50.0
0.
LOAD (LB)
10.0
11.0
12.0
13.0
14.0
15.0
16.0
17.0
18.0
19.0
20.0
DEFLECTION (MICRO-INCHES)
X1000


FIXTURE BEARING TEST
TEST 13705 RUN 4
Y-AXIS CH 51 YMAX = .2862E 03 YMIN = -.6589E 00
X-AXIS CH 50 XMAX = .6274E 04 XMIN = .5536E 04
09:01 12/11/80
DEFLECTION OF FIXTURE ALONE
450. 400. 350. 300. 250. 200. 150. 100. 50.0 0. -50.0
LOAD (LB)
5.50 5.60 5.70 5.80 5.90 6.00 6.10 6.20 6.30 6.40 6.50
X1000
DEFLECTION (MICRO-INCHES)



STIFFNESS OF CLIP GAGE 632.02B01

TABLE A-1. COMPLIANCE COEFFICIENTS

TENSION TESTS IN FIBER DIRECTION (1-DIR.)

STRESS RANGE (ksi)	SPECIMEN	TEST NO.	GAGE	COMPLIANCE $S_{ij} = \partial e_i / \partial \sigma_j$ ($\mu\epsilon$/psi)		
				S_{11}	S_{21}	S_{31}
0 - 10	0° No. 1	11672/2	1+3	0.05091	-0.01519	
			2+4	0.05092		-0.01525
	0° No. 2	11767/1	1+3	0.05136	-0.01715	
			2+4	0.05022		-0.01877
	"	11767/2	1+3	0.05192	-0.01699	
			2+4	0.04945		-0.01801
	0° No. 3	12046/4	1+3	0.04881	-0.01742	
			2+4	0.04802		-0.01566
10 - 40	0° No. 1	11672/2	1+3	0.04834	-0.01488	
			2+4	0.04795		-0.01484
	0° No. 2	11767/1	1+3	0.04817	-0.01475	
			2+4	0.04698		-0.01505
	"	11767/2	1+3	0.04826	-0.01473	
			2+4	0.04758		-0.01498
	0° No. 3	12046/4	1+3	0.04717	-0.01556	
			2+4	0.04674		-0.01410
40 - 50	0° No. 1	11672/2	1+3	0.04657	-0.01486	
			2+4	0.04553		-0.01481
	0° No. 2	11767/1	1+3	0.04648	-0.01456	
			2+4	0.04584		-0.01504
		11767/2	1+3	0.04710	-0.01445	
			2+4	0.04621		-0.01497
10 - 40	N			8	4	4
	MEAN			0.0461	-0.0150	-0.0147
	COEF. VAR'N			0.014	0.027	0.030

TABLE A-2. COMPLIANCE COEFFICIENTS

COMPRESSION TESTS IN FIBER DIRECTION (1-DIR.)

SPECIMEN	TEST NO.	STRESS RANGE (ksi)	GAGE	COMPLIANCE $S_{ij} = \partial e_i / \partial \sigma_j$ ($\mu\epsilon$/psi)		
				S_{11}	S_{21}	S_{31}
0° No. 2	11851/4	1-6	1+3 2+4	0.04952 0.04846	-0.01454	-0.01465
0° No. 2	11851/5	1-10	1+3 2+4	0.05018 0.04901	-0.01560	-0.01583
0° No. 3	12046/2	5-11	1+3 2+4	0.04957 0.04878	-0.01530	-0.01390
N				6	3	3
MEAN				0.0492	-0.0151	-0.0148
COEF. VAR'N				0.016	0.036	0.066

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TABLE A-3. COMPLIANCE COEFFICIENTS
TENSION TESTS IN-PLANE, TRANSVERSE (2-DIR)

SPECIMEN	TEST NO.	STRESS RANGE (ksi)	GAGE	COMPLIANCE $S_{ij} = \partial e_i / \partial \sigma_j$ ($\mu\epsilon$/psi) S_{22}	S_{12}	S_{32}
90° No. 1	11676/2	0-3	1+3	0.6486	-0.01604	
			2+4	0.6484		-0.3104
90° No. 2	11761/1	0-3	1+3	0.6397	-0.01563	
			2+4	0.6312		-0.3056
	11761/2	0-6	1+3	0.6537	-0.01559	
			2+4	0.6575		-0.3078
	11763/1	0-6	1+3	0.6386	-0.01541	
			2+4	0.6420		-0.3049
	11763/2	0-5	1+3	0.6351	-0.01539	
			2+4	0.6360		-0.3067
90° No. 3	12053/1	0-4	1+3	0.6385	-0.01527	
			2+4	0.6417		-0.3050
	N			12	6	6
	MEAN			0.643	-0.0156	-0.307
	COEF. VAR'N			0.012	0.036	0.007

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TABLE A-4. COMPLIANCE COEFFICIENTS
COMPRESSION TESTS IN-PLANE, TRANSVERSE (2-DIR)

SPECIMEN	TEST NO.	STRESS RANGE (ksi)	GAGE	COMPLIANCE $S_{ij} = \partial e_i / \partial \sigma_j$ ($\mu\epsilon$/psi)		
				S_{22}	S_{12}	S_{32}
90° No. 1	11676/5	1 - 2	1+3	0.6276	-0.01473	
			2+4	0.6341		-0.3022
	11676/6	1 - 3	1+3	0.6413	-0.01373	
			2+4	0.6369		-0.2918
90° No. 2	12037/2	1 - 3	1+3	0.6159	-0.01544	
			2+4	0.6124		-0.2967
	N			6	3	3
	MEAN			0.628	-0.0146	-0.297
	COEF. VAR'N			0.019	0.059	0.018

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TABLE A-5. COMPLIANCE COEFFICIENTS
COMPRESSION TESTS IN THICKNESS DIRECTION (3-DIR)

SPECIMEN	TEST NO.	STRESS RANGE (ksi)	GAGE	COMPLIANCE $S_{ij} = \partial e_i/\partial \sigma_j$ ($\mu\epsilon$/psi)		
				S_{33}	S_{13}	S_{23}
0° No. 2 (5-TIER)	12032/5	5 - 10	2+4	0.6608	-0.0175	
	12032/6	6 - 19	2+4	0.6722	-0.0178	
90° No. 2 (3-TIER)	12055/2	5 - 9	2+4	0.6633		-0.3522
	12055/3	2 - 12	2+4	0.6658		-0.3591
	12058/5	8 - 18	2+4	0.6602		-0.3589
90-90-2 (17-TIER)	13054/4	1 - 3	1+3	0.6705	-0.0161	
			2+4	0.6878		-0.3330
	13054/5	2 - 6	1+3	0.6752	-0.0153	
			2+4	0.6794		-0.3274
N				9	4	5
MEAN				0.671	-0.0167	-0.346
COEF. VAR'N				0.014	0.072	0.043

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0-DEGREE BEAM LOADED IN 2 DIR   L= 2.024   FN IN FFBANK 20

Exx= 21100000. Eyy= 0 Ezz= 1550000. Gxz= 650000. Vxz= .31 Vxy= .31 Vzy= .49 820106
PLANE STRESS: Kx= .062811 , Kz= .85504 Sh= 185.529 P= 100
L= 2.024 h= .2691 W= .2695 L1= .54 Lp= .0135 ip= 0 aa= .027 bb= .013455

FN matrix is

0	0.008775	0.000000	0.008529	0.030890	0.064549	0.107483	0.157991	0.214591	0.275964	0.340907	0.408299	0.477076	0.546204
1	0.008682	0.000000	0.008462	0.030695	0.064192	0.106937	0.157231	0.213595	0.274707	0.339358	0.406421	0.474820	0.543503
2	0.008521	0.000000	0.008275	0.030148	0.063182	0.105389	0.155084	0.210787	0.271177	0.335037	0.401230	0.468665	0.536270
3	0.008222	0.000000	0.008002	0.029335	0.061668	0.103061	0.151849	0.206565	0.265889	0.328604	0.393567	0.459680	0.525862
4	0.007927	0.000000	0.007681	0.028354	0.059818	0.100198	0.147861	0.201361	0.259385	0.320724	0.384237	0.448826	0.513411
5	0.007562	0.000000	0.007342	0.027287	0.057778	0.097014	0.143407	0.195536	0.252107	0.311922	0.373850	0.436799	0.499696
6	0.007250	0.000000	0.007004	0.026192	0.055652	0.093664	0.138693	0.189351	0.244368	0.302563	0.362819	0.424056	0.485214
7	0.006898	0.000000	0.006678	0.025105	0.053505	0.090248	0.133855	0.182977	0.236373	0.292884	0.351409	0.410886	0.470269
8	0.006614	0.000000	0.006367	0.024040	0.051372	0.086822	0.128972	0.176517	0.228246	0.283028	0.339781	0.397463	0.455044
9	0.006292	0.000000	0.006072	0.023004	0.049270	0.083416	0.124088	0.170026	0.220058	0.273078	0.328029	0.383888	0.439646
10	0.006034	0.000000	0.005788	0.021994	0.047200	0.080039	0.119220	0.163534	0.211845	0.263079	0.316204	0.370219	0.424138
11	0.005734	0.000000	0.005515	0.021007	0.045161	0.076693	0.114376	0.157052	0.203626	0.253054	0.304334	0.356488	0.408553
12	0.005493	0.000000	0.005247	0.020037	0.043148	0.073374	0.109556	0.150585	0.195408	0.243016	0.292436	0.342715	0.392914
13	0.005205	0.000000	0.004985	0.019082	0.041158	0.070083	0.104761	0.144137	0.187200	0.232976	0.280522	0.328914	0.377236
14	0.004973	0.000000	0.004727	0.018141	0.039191	0.066821	0.099997	0.137715	0.179010	0.222945	0.268607	0.315101	0.361537
15	0.004673	0.000000	0.004474	0.017215	0.037251	0.063595	0.095272	0.131333	0.170856	0.212941	0.256709	0.301294	0.345834
16	0.004472	0.000000	0.004226	0.016309	0.035346	0.060417	0.090604	0.125011	0.162759	0.202989	0.244854	0.287519	0.330151
17	0.004208	0.000000	0.003989	0.015432	0.033491	0.057306	0.086017	0.118777	0.154751	0.193120	0.233073	0.273806	0.314517
18	0.004011	0.000000	0.003765	0.014593	0.031700	0.054283	0.081534	0.112656	0.146860	0.183364	0.221395	0.260181	0.298955
19	0.003778	0.000000	0.003559	0.013798	0.029982	0.051356	0.077166	0.106662	0.139098	0.173734	0.209832	0.246658	0.283478
20	0.003615	0.000000	0.003368	0.013043	0.028327	0.048516	0.072902	0.100782	0.131454	0.164218	0.198375	0.233228	0.268079
21	0.003408	0.000000	0.003188	0.012312	0.026713	0.045731	0.068707	0.094980	0.123892	0.154783	0.186992	0.219862	0.252731

0	0.408299	0.477076	0.546204	0.614657	0.681404	0.745385	0.805500	0.860587	0.909386	0.950467	0.981959	1.000000	0.981735
1	0.406421	0.474820	0.543503	0.611421	0.677500	0.740619	0.799575	0.853039	0.899476	0.936995	0.963008	0.973320	0.962789
2	0.401230	0.468665	0.536270	0.602968	0.667652	0.729156	0.786226	0.837473	0.881308	0.915832	0.938640	0.946640	0.938416
3	0.393567	0.459680	0.525862	0.591022	0.654044	0.713750	0.768879	0.818049	0.859701	0.892029	0.912893	0.919960	0.912674
4	0.384237	0.448826	0.513411	0.576902	0.638185	0.696091	0.749374	0.796676	0.836494	0.867129	0.886677	0.893281	0.886453
5	0.373850	0.436799	0.499696	0.561462	0.620993	0.677134	0.728663	0.774258	0.812475	0.841720	0.860284	0.866601	0.860066
6	0.362819	0.424056	0.485214	0.545226	0.603003	0.657411	0.707255	0.751253	0.788020	0.816061	0.833824	0.839921	0.833600
7	0.351409	0.410886	0.470269	0.528507	0.584530	0.637228	0.685433	0.727907	0.763322	0.790275	0.807340	0.813241	0.807121
8	0.339781	0.397463	0.455044	0.511493	0.565760	0.616760	0.663358	0.704355	0.738485	0.764425	0.780850	0.786561	0.780625
9	0.328029	0.383888	0.439646	0.494293	0.546801	0.596110	0.641120	0.680676	0.713566	0.738541	0.754360	0.759881	0.754141
10	0.316204	0.370219	0.424138	0.476970	0.527714	0.575338	0.618775	0.656913	0.688595	0.712638	0.727871	0.733201	0.727646
11	0.304334	0.356488	0.408553	0.459562	0.508538	0.554479	0.596353	0.633091	0.663588	0.686722	0.701383	0.706522	0.701164
12	0.292436	0.342715	0.392914	0.442091	0.489295	0.533555	0.573875	0.609226	0.638556	0.660797	0.674896	0.679842	0.674671
13	0.280522	0.328914	0.377236	0.424574	0.470002	0.512582	0.551353	0.585329	0.613505	0.634865	0.648408	0.653162	0.648189
14	0.268607	0.315101	0.361537	0.407027	0.450675	0.491575	0.528801	0.561408	0.588439	0.608928	0.621920	0.626482	0.621695
15	0.256709	0.301294	0.345834	0.389468	0.431331	0.470548	0.506229	0.537472	0.563364	0.582987	0.595432	0.599802	0.595212
16	0.244854	0.287519	0.330151	0.371920	0.411989	0.449517	0.483651	0.513531	0.538287	0.557046	0.568944	0.573122	0.568718
17	0.233073	0.273806	0.314517	0.354406	0.392669	0.428499	0.461082	0.489595	0.513213	0.531107	0.542457	0.546443	0.542238
18	0.221395	0.260181	0.298955	0.336948	0.373391	0.407511	0.438532	0.465672	0.488147	0.505175	0.515973	0.519763	0.515748
19	0.209832	0.246658	0.283478	0.319558	0.354164	0.386560	0.416008	0.441767	0.463094	0.479250	0.489492	0.493083	0.489273
20	0.198375	0.233228	0.268079	0.302230	0.334984	0.365643	0.393507	0.417877	0.438051	0.453330	0.463014	0.466403	0.462788
21	0.186992	0.219862	0.252731	0.284941	0.315831	0.344743	0.371016	0.393992	0.413010	0.427411	0.436535	0.439723	0.436315

0-DEGREE BEAM LOADED IN 2-DIR L= 2.024 FN IN FFBANK 20

Exx= 21100000. Eyy= 0 Ezz= 1550000. Gxz= 650000. Vxz= .31 Vxy= .31 Vzy= .49 820106
PLANE STRESS: Kx= .062811 , Kz= .85504 Sh= 185.529 P= 100
l= 2.024 h= .2691 W= .2695 L1= .54 Lp= .0135 ip= 0 aa= .027 bb= .013455

Axial stresses are:

0	17.9462	14.3451	11.7181	9.6190	7.8540	6.3190	4.9500	3.7023	2.5405	1.4361	0.3634	-0.6990	-1.7704
1	17.7803	14.2823	11.6810	9.5916	7.8299	6.2949	4.9235	3.6710	2.5015	1.3854	0.2951	-0.7941	-1.9069
2	17.4189	14.1036	11.5743	9.5141	7.7645	6.2327	4.8592	3.5999	2.4195	1.2878	0.1765	-0.9405	-2.0891
3	16.8263	13.8257	11.4076	9.3963	7.6698	6.1485	4.7781	3.5173	2.3318	1.1921	0.0707	-1.0581	-2.2191
4	16.1865	13.4748	11.1917	9.2460	7.5544	6.0524	4.6927	3.4376	2.2548	1.1160	-0.0051	-1.1328	-2.2907
8	13.4627	11.7252	10.0174	8.4192	6.9484	5.5951	4.3407	3.1646	2.0455	0.9625	-0.1043	-1.1738	-2.2632
12	11.1387	9.8969	8.6301	7.3795	6.1755	5.0279	3.9348	2.8886	1.8784	0.8917	-0.0836	-1.0595	-2.0463
16	9.0203	8.1487	7.2130	6.[illegible]565	5.3070	4.3760	3.4654	2.5735	1.6964	0.8290	-0.0337	-0.8960	-1.7622
17	8.5008	7.7311	6.8623	[illegible].7687	5.0775	4.1989	3.3346	2.4834	1.6425	0.8085	-0.0223	-0.8527	-1.6858
18	8.0640	7.3253	6.5131	5.6777	4.8420	4.0144	3.1960	2.3862	1.5828	0.7840	-0.0130	-0.8097	-1.6079
19	7.6096	6.9282	6.1651	5.3833	4.6005	3.8223	3.0494	2.2813	1.5168	0.7548	-0.0064	-0.7672	-1.5288
20	7.2421	6.5404	5.8177	5.0860	4.3537	3.6236	2.8955	2.1695	1.4449	0.7213	-0.0021	-0.7254	-1.4489

0	-2.8679	-4.0092	-5.2156	-6.5208	-8.0039	-9.9452	-13.9505	-37.6532
1	-3.0701	-4.3170	-5.6963	-7.2882	-9.2477	-11.9344	-16.2824	-21.6170
2	-3.2973	-4.5988	-6.0395	-7.6873	-9.6565	-12.1502	-15.3575	-16.8270
3	-3.4382	-4.7459	-6.1812	-7.7969	-9.6701	-11.8892	-14.3087	-14.8859
4	-3.5024	-4.7952	-6.2017	-7.7624	-9.5238	-11.4979	-13.4254	-13.9294
8	-3.3885	-4.5656	-5.8080	-7.1219	-8.4943	-9.8684	-11.1113	-12.0789
12	-3.0529	-4.0869	-5.1523	-6.2454	-7.3518	-8.4443	-9.4924	-10.4926
16	-2.6355	-3.5188	-4.4130	-5.3149	-6.2184	-7.1160	-8.0057	-8.9010
17	-2.5235	-3.3683	-4.2203	-5.0773	-5.9349	-6.7881	-7.6379	-8.4939
18	-2.4091	-3.2145	-4.0245	-4.8375	-5.6503	-6.4601	-7.2693	-8.0936
19	-2.2922	-3.0577	-3.8258	-4.5954	-5.3644	-6.1318	-6.8993	-7.6751
20	-2.1732	-2.8981	-3.6244	-4.3509	-5.0772	-5.8026	-6.5286	-7.2634

Transverse stresses are:

0	0.0000	-0.0344	-0.1000	-0.1840	-0.2816	-0.3912	-0.5127	-0.6474	-0.7977	-0.9673	-1.1622	-1.3909	-1.6669
1	0.0000	-0.0311	-0.0909	-0.1681	-0.2577	-0.3575	-0.4668	-0.5855	-0.7141	-0.8533	-1.0042	-1.1676	-1.3437
2	0.0000	-0.0219	-0.0684	-0.1299	-0.2013	-0.2800	-0.3642	-0.4526	-0.5438	-0.6365	-0.7287	-0.8176	-0.8994
3	0.0000	-0.0127	-0.0435	-0.0865	-0.1375	-0.1937	-0.2529	-0.3131	-0.3726	-0.4295	-0.4815	-0.5261	-0.5600
4	0.0000	-0.0044	-0.0219	-0.0490	-0.0827	-0.1203	-0.1599	-0.1995	-0.2376	-0.2724	-0.3023	-0.3255	-0.3400
8	0.0000	0.0040	0.0074	0.0077	0.0049	-0.0005	-0.0077	-0.0158	-0.0242	-0.0321	-0.0391	-0.0445	-0.0479
12	0.0000	0.0015	0.0039	0.0060	0.0070	0.0066	0.0049	0.0024	-0.0007	-0.0040	-0.0072	-0.0099	-0.0118
16	0.0000	0.0027	0.0075	0.0128	0.0174	0.0208	0.0226	0.0227	0.0215	0.0191	0.0159	0.0124	0.0090
17	0.0000	0.0034	0.0098	0.0165	0.0224	0.0268	0.0293	0.0300	0.0289	0.0263	0.0227	0.0186	0.0145
18	0.0000	0.0046	0.0115	0.0186	0.0249	0.0297	0.0326	0.0335	0.0325	0.0299	0.0262	0.0218	0.0173
19	0.0000	0.0040	0.0102	0.0166	0.0223	0.0267	0.0294	0.0303	0.0295	0.0273	0.0239	0.0260	0.0159
20	0.0000	0.0026	0.0062	0.0103	0.0144	0.0178	0.0201	0.0210	0.0206	0.0189	0.0163	0.0132	0.0100

0	-2.0106	-2.4548	-3.0518	-3.8876	-5.1046	-6.9393	-9.7620	-13.7429
1	-1.5312	-1.7249	-1.9121	-2.0652	-2.1268	-1.9811	-1.3949	0.0000
2	-0.9683	-1.0157	-1.0297	-0.9937	-0.8857	-0.6797	-0.3552	0.0000
3	-0.5795	-0.5799	-0.5559	-0.5020	-0.4122	-0.2826	-0.1208	-0.0000
4	-0.3438	-0.3347	-0.3105	-0.2692	-0.2092	-0.1312	-0.0457	0.0000
8	-0.0489	-0.0469	-0.0416	-0.0329	-0.0213	-0.0089	-0.0001	-0.0000
12	-0.0128	-0.0126	-0.0111	-0.0084	-0.0050	-0.0019	-0.0001	0.0000
16	0.0059	0.0036	0.0020	0.0012	0.0009	0.0007	0.0003	-0.0000
17	0.0107	0.0075	0.0051	0.0034	0.0023	0.0015	0.0007	0.0000
18	0.0131	0.0095	0.0067	0.0046	0.0030	0.0018	0.0008	0.0000
19	0.0121	0.0087	0.0060	0.0040	0.0026	0.0015	0.0007	-0.0000
20	0.0070	0.0044	0.0025	0.0012	0.0005	0.0000	-0.0001	0.0000

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0-DEGREE BEAM LOADED IN Z-DIR    L= 2.024        FN IN FFBANK  20

Exx= 21100000.   Eyy= 0   Ezz= 1550000.   Gxz= 650000.   Vxz= .31   Vxy= .31   Vzy= .49     820106
PLANE STRESS   Kx= .062811 , Kz= .85504   Sh= 185.529   F= 100
L= 2.024   h= .2691   W= .2675   L1= .54   Lp= .0135   ip= 0   aa= .027   bb= .013455
```

Shear stresses are:

0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	-0.0000	0.0958	0.1438	0.1748	0.1990	0.2209	0.2429	0.2670	0.2948	0.3284	0.3701	0.4235	0.4933
2	-0.0000	0.1757	0.2667	0.3251	0.3694	0.4075	0.4439	0.4811	0.5214	0.5666	0.6187	0.6795	0.7513
3	-0.0000	0.2319	0.3579	0.4389	0.4985	0.5472	0.5904	0.6313	0.6721	0.7140	0.7580	0.8046	0.8537
4	0.0000	0.2646	0.4173	0.5166	0.5881	0.6438	0.6900	0.7304	0.7670	0.8011	0.8331	0.8629	0.8896
8	0.0000	0.2714	0.4688	0.6112	0.7148	0.7907	0.8460	0.8858	0.9129	0.9293	0.9357	0.9323	0.9183
12	-0.0000	0.2487	0.4488	0.6053	0.7250	0.8148	0.8801	0.9255	0.9542	0.9685	0.9697	0.9580	0.9327
16	-0.0000	0.2304	0.4231	0.5821	0.7100	0.8099	0.8850	0.9385	0.9731	0.9907	0.9924	0.9786	0.9490
17	-0.0000	0.2217	0.4115	0.5708	0.7008	0.8038	0.8824	0.9393	0.9768	0.9966	0.9996	0.9863	0.9563
18	0.0000	0.2111	0.3980	0.5578	0.6901	0.7965	0.8789	0.9396	0.9804	1.0028	1.0075	0.9949	0.9647
19	0.0000	0.2002	0.3846	0.5450	0.6795	0.7890	0.8752	0.9396	0.9838	1.0087	1.0152	1.0033	0.9730
20	0.0000	0.1920	0.3744	0.5348	0.6707	0.7826	0.8717	0.9393	0.9863	1.0137	1.0217	1.0105	0.9802

0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.5865	0.7134	0.8895	1.1375	1.4887	1.9693	2.4193	0.0000
2	0.8361	0.9354	1.0492	1.1730	1.2890	1.3360	1.0845	0.0000
3	0.9043	0.9544	0.9991	1.0286	1.0215	0.9237	0.6017	0.0000
4	0.9116	0.9259	0.9271	0.9057	0.8422	0.6954	0.3941	0.0000
8	0.8920	0.8506	0.7898	0.7033	0.5819	0.4166	0.2100	0.0000
12	0.8926	0.8353	0.7578	0.6568	0.5291	0.3736	0.1942	0.0000
16	0.9026	0.8379	0.7532	0.6466	0.5171	0.3647	0.1913	0.0000
17	0.9088	0.8427	0.7564	0.6485	0.5183	0.3658	0.1924	0.0000
18	0.9163	0.8488	0.7609	0.6517	0.5206	0.3678	0.1940	0.0000
19	0.9238	0.8550	0.7658	0.6553	0.5233	0.3699	0.1957	0.0000
20	0.9302	0.8603	0.7697	0.6580	0.5251	0.3712	0.1965	0.0000

Deformations are:

Sta	(du/dz)fx	(du/dz)fz	gamma	(wb)fx	(wb)fz	ws	wt
0	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
1	-0.00010216	0.00000545	0.00056946	0.00000138	-0.00000007	0.00000771	0.00000901
2	-0.00020658	0.00000913	0.00095181	0.00000554	-0.00000028	0.00002907	0.00003433
3	-0.00031284	0.00001106	0.00116617	0.00001255	-0.00000055	0.00005759	0.00006959
4	-0.00041941	0.00001221	0.00128169	0.00002243	-0.00000087	0.00009115	0.00011271
5	-0.00052571	0.00001275	0.00134738	0.00003520	-0.00000120	0.00012636	0.00016035
6	-0.00063085	0.00001322	0.00138878	0.00005081	-0.00000156	0.00016369	0.00021294
7	-0.00073476	0.00001342	0.00141774	0.00006925	-0.00000192	0.00020124	0.00026857
8	-0.00083688	0.00001370	0.00143958	0.00009047	-0.00000228	0.00024018	0.00032837
9	-0.00093729	0.00001380	0.00145677	0.00011443	-0.00000265	0.00027894	0.00039071
10	-0.00103552	0.00001400	0.00147066	0.00014107	-0.00000303	0.00031882	0.00045686
11	-0.00113172	0.00001404	0.00148212	0.00017033	-0.00000341	0.00035833	0.00052525
12	-0.00122544	0.00001421	0.00149184	0.00020216	-0.00000379	0.00039884	0.00059721
13	-0.00131690	0.00001422	0.00150047	0.00023648	-0.00000418	0.00043888	0.00067118
14	-0.00140566	0.00001437	0.00150869	0.00027324	-0.00000456	0.00047986	0.00074855
15	-0.00149192	0.00001438	0.00151720	0.00031236	-0.00000495	0.00052035	0.00082776
16	-0.00157523	0.00001454	0.00152678	0.00035378	-0.00000533	0.00056180	0.00091024
17	-0.00165578	0.00001458	0.00153784	0.00039740	-0.00000573	0.00060281	0.00099447
18	-0.00173306	0.00001477	0.00155000	0.00044316	-0.00000612	0.00064485	0.00108189
19	-0.00180722	0.00001482	0.00156184	0.00049096	-0.00000653	0.00068651	0.00117093
20	-0.00187772	0.00001499	0.00157132	0.00054072	-0.00000692	0.00072917	0.00126277
21	-0.00248087	0.00001497	0.00159102	0.00161679	-0.00001400	0.00148013	0.00308293

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T300/5208 GRAPHITE-EPOXY IN
SIMPLE BENDING

APPROVALS

J. Fairchild

DIVISION ENGINEER J. Fairchild

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